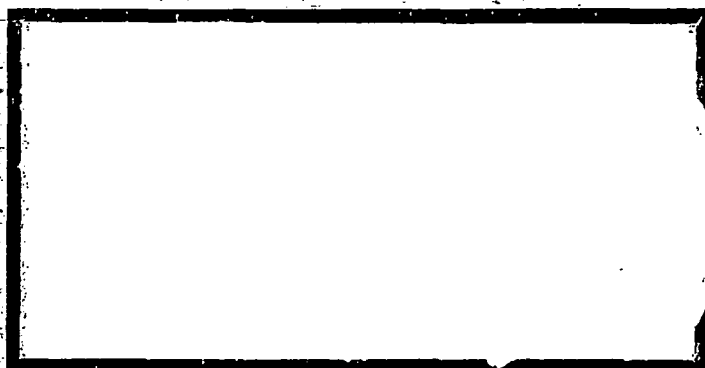


CR-134173



(NASA-CR-134173) SHUTTLE MISSION  
SIMULATOR BASELINE DEFINITION REPORT,  
VOLUME 1 (Singer Co., Binghamton, N.Y.)

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CSCL 14B

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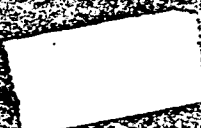


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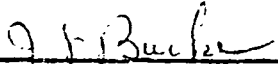


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BASELINE DEFINITION REPORT

VOLUME I    DECEMBER 21, 1973

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\_\_\_\_\_  
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This document is submitted in compliance  
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List as Type I Data, Contract NAS9-12836

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SLA-73-0053

FUSED SALTS, A Bibliography

December 1972

Compiled by: Michael Schalit  
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Volume II: SYMBOLS AND FORMULAE INDEX

ABSTRACT

This publication merges the bibliographic data given in Reference Numbers 7001-9700--data of SC-R-72-2770 plus additional citations from Chemical Abstracts compiled since publication of that report. Therefore SLA-73-0053 supersedes SC-R-72-2770 and provides the supplementary access points of symbols and formulae, descriptive terms, and authors.

## PREFACE

Beginning with January 1, 1973, all Sandia Laboratories originated reports will have the designation of SLA (Sandia Laboratories, Albuquerque) or SLL (Sandia Laboratories, Livermore).


This report, SLA-73-0053, supersedes the previous Fused Salts Bibliography, SC-R-72-2770, and contains citations compiled since the publication of that report. This later document will also be divided into the following four volumes: Citations Listing, Symbols and Formulae Index, Descriptive Terms Index, and Authors Index.

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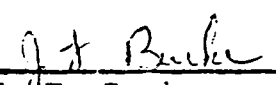
SHUTTLE MISSION SIMULATOR  
BASELINE DEFINITION REPORT

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This document is submitted in compliance with  
Line Item No. 8 of the Data Requirements List  
as Type I Data, Contract NAS9-12836

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#### 3.3.4-1 FBCS OBC Simulation

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## 1.0 Introduction

The purpose of this report is to provide a detailed baseline definition of the Shuttle Mission Simulator. Included in Volume I are:

- a) Physical arrangement of the complete simulator system in the appropriate facility, with a definition of required facility modifications.
- b) Functional descriptions of all hardware units, including the operational features, data demands, and facility interfaces.
- c) Description of the hardware features necessary to integrate the above described items into a baseline simulator system, including, where appropriate, a rationale for the selection of the chosen implementation.
- d) Operating, maintenance, and configuration updating characteristics of the SMS hardware.

Volume II includes:

- a) A functional description of all software blocks including their structural and operational characteristics.
- b) A description of data processing hardware and software features needed to integrate the above described item into a baseline simulator system.
- c) Operation, maintenance, configuration updating, and configuration control characteristics of the SMS software.
- d) Cost and schedule information.

### 1.1 Reference Documents

The following documents have been used as reference in identifying the requirements of the SMS.

1. Shuttle Vehicle and Mission Simulation Requirements Report
2. Shuttle Mission Simulator Requirements Report
3. Shuttle Mission Simulation Training Requirements Report
4. Shuttle Mission Simulator Hardware Conceptual Design Report
5. Shuttle Mission Simulator Software Conceptual Design Report
6. MIL-STD-1310 Shipboard Bonding and other techniques for Electromagnetic Compatibility and Safety
7. MIL-B-5087 Bonding, Electrical, and Lighting Protection, for Aerospace System
8. NHB 5320.3 Electromagnetic Compatibility Principles and Practices

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## 2.0 SMS General Configuration

The SMS must provide training for Shuttle Vehicle crew members and Mission Control Center personnel in all mission phases and vehicle operating modes in the most efficient and economical manner possible.

From a simulator hardware viewpoint, consideration must be given to the requirements and existing state-of-the-art capabilities of motion system hardware, visual system, crew station hardware, Instructor Operator Station hardware, Digital Computation Systems, and Data Conversion Equipment.

An in depth analysis of the Shuttle Mission Simulator training requirements has been made as part of the SMSR Report generation analysis and the Hardware and Software Conceptual Design Reports. As a result, a definition of the training devices required in the SMS complex has been determined, and serves as a starting point for this report. In conjunction with the training requirements analysis, a crew station, motion system and visual system trade study was also conducted which arrived at the conclusion that state-of-the-art motion systems could not support a replica of the entire Orbiter upper crew station, a forward and aft visual system, and provide the vertical crew station attitudes required for launch and launch abort training. As a result of these studies and subsequent review meetings with the NASA, the SMS complex has been specified to consist of two independent crew stations.

One crew station, which will be referred to as the Motion Base Crew Station (MBCS), will be used to train the commander and pilot in all

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phases of the mission except Docking and Payload Handling operations. The second crew station, which will be referred to as the Fixed Base Crew Station (FBCS), will provide training for the Commander, Pilot, Mission Specialist, and Payload Specialist at all upper crew compartment work stations in all mission phases. Refer to Figure 2.0-1, which identifies the major equipment areas of the SMS. Figures 2.0-2 thru 2.0-8 define the specification tree for the MBCS and FECS in more detail.

The MBCS will be mounted on a six DOF motion system provided with a tilt capability to simulate ascent. A visual system will provide the scenes required for those phases of the mission listed above. The FECS will be mounted on a fixed platform. A forward and an aft visual system will be included to provide the scenes required for all mission phases.

Training in the MBCS will be conducted independent of the FBCS and vice versa. Training on different exercises can be conducted simultaneously in both crew stations. Current planning calls for the MBCS to be required earlier than the FBCS and to support the initial two man vertical flight tests. When the FECS becomes operational, it will be used primarily for on-orbit training due to the lack of motion cues considered necessary for aerodynamic flight training in an airplane type vehicle such as the Orbiter. However, the capability to provide training in the FBCS during the aerodynamic flight regimes is a requirement in order to provide back-up capability in case the

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MBCS is not operational due to maintenance or modification requirements and to handle integrated (MCC) exercises if crew procedures subsequently require three or four man participation during the aerodynamic flight regimes. Conversely, the primary function of the MBCS will be to provide Commander/Pilot training for launch, launch aborts, entries and ferry flights. Thus significant cost savings may be effected if the SMS design philosophy recognizes the primary and back-up roles of each crew station. These savings can be brought about by sharing equipment between the two crew stations which are unique to the orbital/sub-orbital mission segments. Potential candidates for sharing are the sub-orbital image generation equipment and the main engine controllers. On-orbit image generation equipment may also be considered, but it may seriously hamper the training flexibility of the MBCS and should only be considered if drastic cost reductions are required.

The SMS complex will also permit training in each crew station while integrated with MCC. The capability to operate both crew stations simultaneously with MCC has not been firmly decided. The key factor influencing this requirement is the capability of the non-SMS interfacing equipment (MCC and the inter-building communication equipment) to permit this type of operation.

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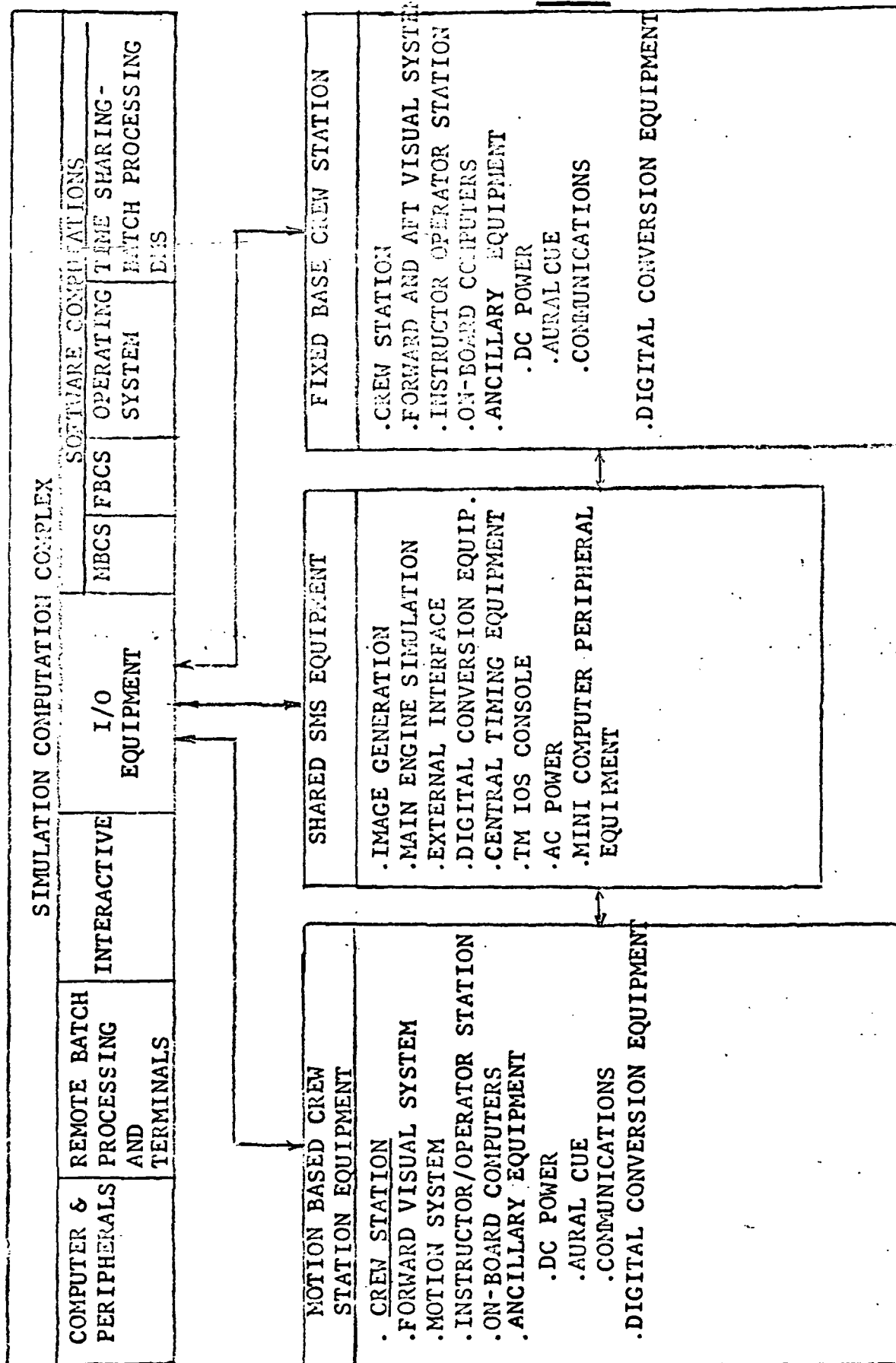


FIGURE 2.0-1  
SHUTTLE MISSION SIMULATOR MAJOR EQUIPMENT AREAS

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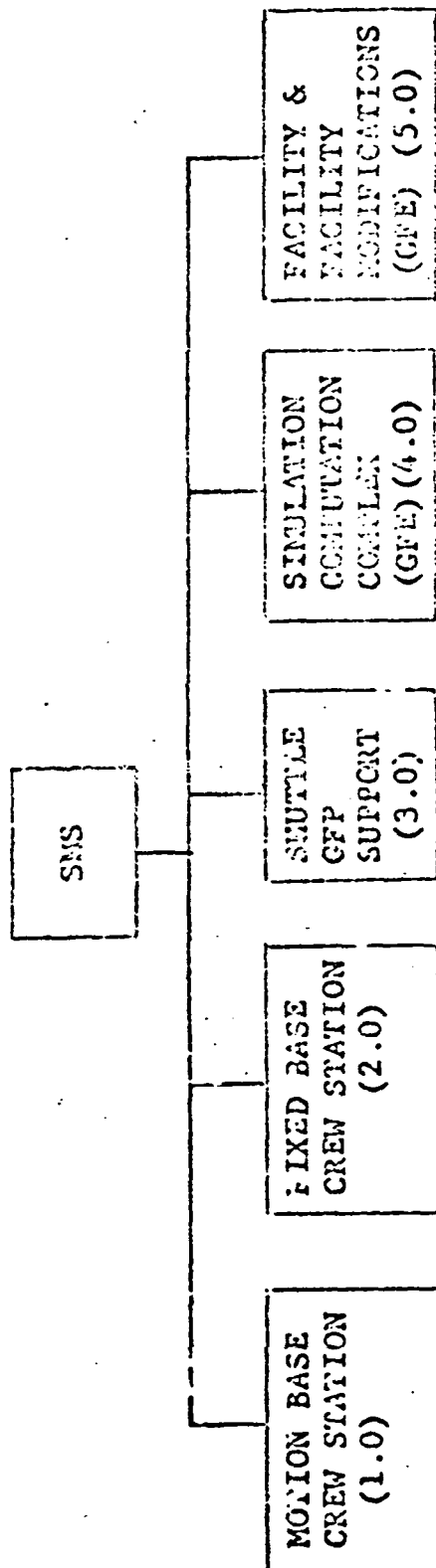


FIGURE 2.0-2 PROGRAM SPECIFICATION TREE



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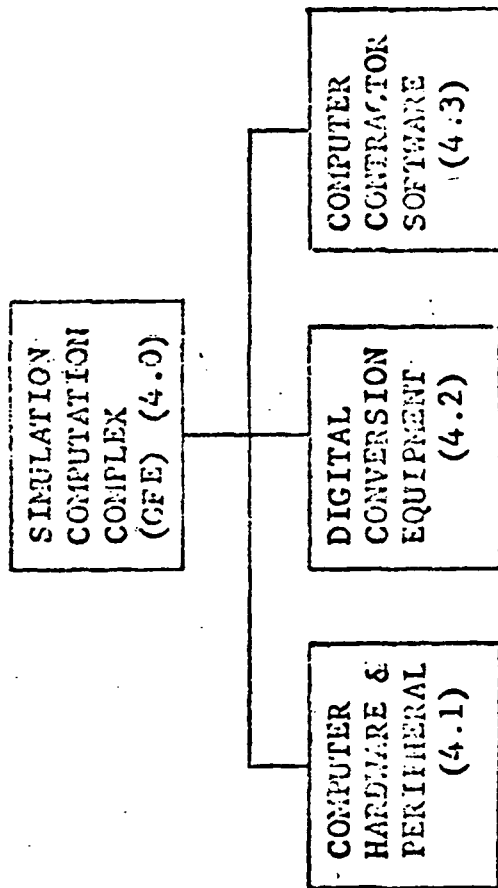


FIGURE 2.0-3 SIMULATION COMPUTATION COMPLEX SPECIFICATION TREE

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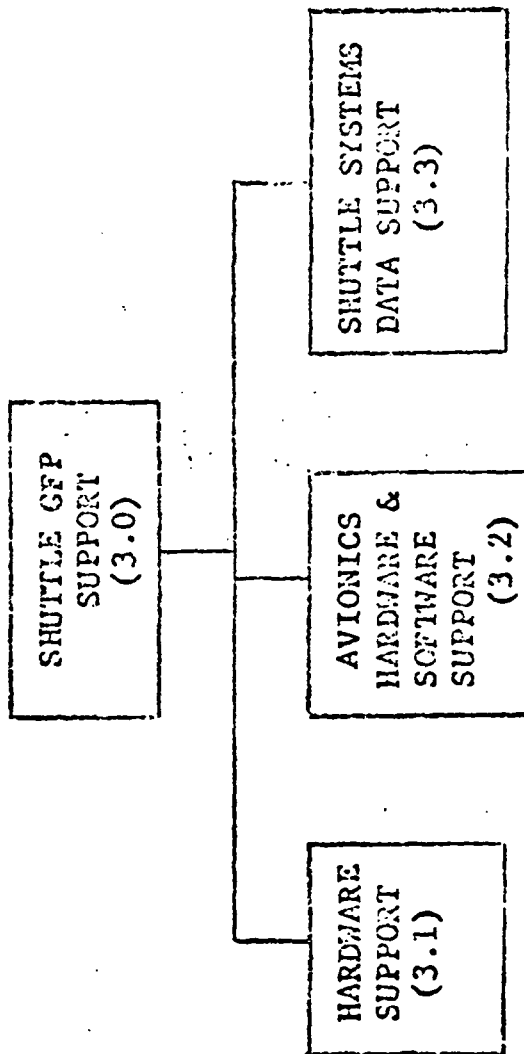


FIGURE 2.0-4 SHUTTLE CONTRACTOR SUPPORT SPECIFICATION TREE

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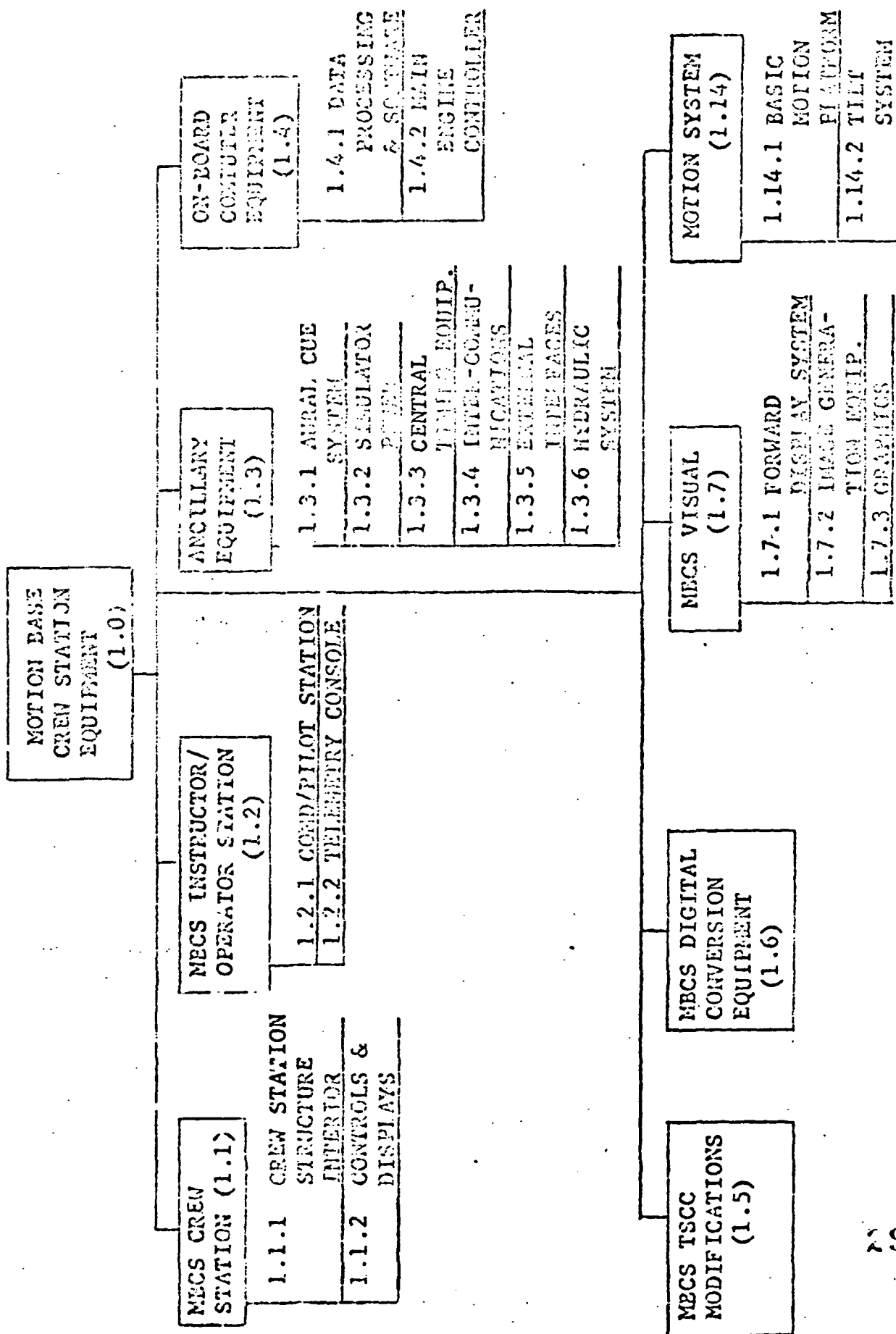
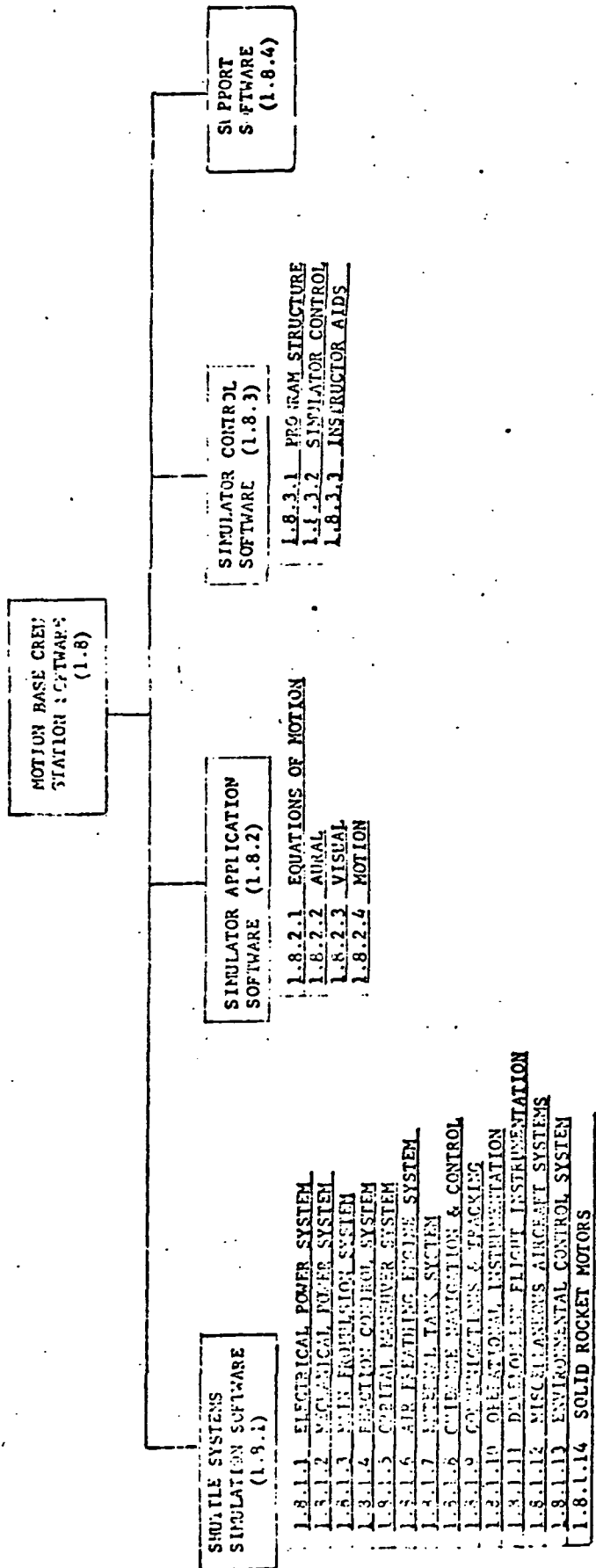


FIGURE 2.0-5 MECS SYSTEM CEI SPECIFICATION TREE



MBCS SOFTWARE CPCEI SPECIFICATION TREE  
FIGURE 2.0-6



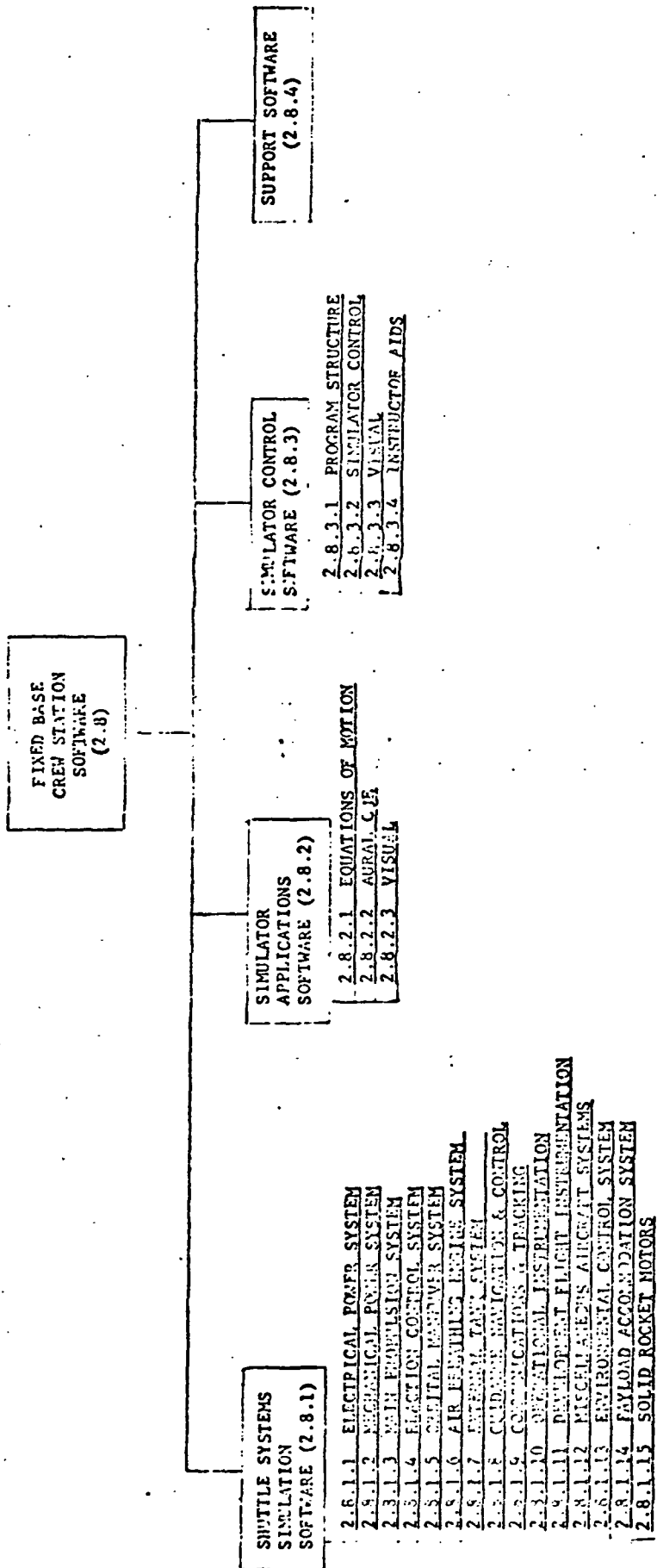


FIGURE 2.0-8 FDCS SOFTWARE CPCEI SPECIFICATION TREE

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## 2.1 External Interfaces

The SMS will be installed in Building 5 at the Johnson Space Center (JSC) in Houston, Texas, and must interface physically and electrically with the structure in which it is housed, and also with the Mission Control Center (MCC) and MCC Simulation Facility (MCCSF) on the site.

Electrical power and cooling air will be provided in the Building. Additional signal interfaces include:

- a) Block I Trajectory Data Interface
- b) Block II Telemetry Data Interface
- c) Command Data Interface
- d) Central Timing Equipment Interface
- e) Voice Communications Interface

The requirements of these interfaces are also described in subsequent sections of this report.

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## 2.2 Hardware Components

The hardware baseline design effort consists of translating the SMSR training, operational, modification and maintenance requirements into lower level definitions, requirements, and actual selection of equipment which will comprise the SMS. As is the case in every new simulation task, the majority of the equipment has to be designed for the application from state-of-the-art electrical and mechanical components.

The SMS equipment for the purposes of further discussion will be classified into four major areas (see Figure 2.0-1 thru 2.0-8).

1. Simulation Computation Complex (SCC) - The SCC will be provided GFP to the SMS and possess the following equipment and capabilities -

- a. Computer Complex & Peripherals - The computer complex will be capable of performing the software required for both create stations and provide the I/O capability to handle the SMS and time-sharing requirements simultaneously.

- b. Remote/Local Batch Processing Stations & Inter-Active Terminals - A local batch processing station will be provided in Bldg. 5, at the host computer complex. Two additional remote batch processing stations will be provided in Bldg. 5 and at the Simulator Contractor Site. Two inter-active terminals will also be provided in Bldg. 4, two in Bldg. 5, and two at the Simulator Contractor Site.



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2. Motion Base Crew Station Equipment - The MBCS equipment will be delivered initially and will therefore have to be designed to have a completely stand-alone capability. However by considering the overall SMS configuration, economies can be effected by sizing some MBCS components to handle both the requirements of the MBCS and the FBCS. The equipment comprising the MBCS will be classified into the following categories for future discussions:

- a) Crew Station
- b) Forward Visual System
- c) Motion System
- d) Instructor Operator Station
- e) On-Board Computer Equipment
- f) Ancillary Equipment
- g) Digital Conversion Equipment

The MBCS baseline design will be treated in Section 3.2 of the report.

3. Fixed Base Crew Station Equipment - The FBCS will be delivered subsequent to the MBCS and as discussed earlier, may make use of surplus MBCS capability and also time share some of the MBCS equipment. The equipment comprising the FBCS will be classified into the following categories for future discussions:

- a) Crew Station
- b) Forward Visual

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- c) Rear Visual
- d) On-Board Computers
- e) Ancillary Equipment
- f) Digital Conversion Equipment

The FBCS baseline design will be discussed in Section 3.3 of the report.

4. Shared SMS Equipment - Current equipment candidates for sharing between the FBCS and MBCS are identified on Figure 2.0-1. Included in this group are the:

- a) Telemetry Console
- b) Main Engine Controller Simulation
- c) External Interface Equipment
- d) Mini Computer Peripheral Equipment
- e) Central Timing Equipment
- f) AC Power Distribution Equipment
- g) Visual Image Generation Equipment

In areas where previous reports have indicated that a preferred design was the overwhelming choice for the SMS or where the trade-offs are more at the detailed design implementation level rather than at the baseline level, only one design will be presented.

For the DCE and On-Board Computer Equipment sections, alternate approaches have been described but one baseline design has been selected.

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## 2.3 SMS Facility Requirements

### 2.3.1 Floor Arrangement

The available floor space for the SMS within the Houston Facility is shown in Figure 2.3.1-1.

Within this area, a viable arrangement has been made as shown in Figure 2.3.1-2.

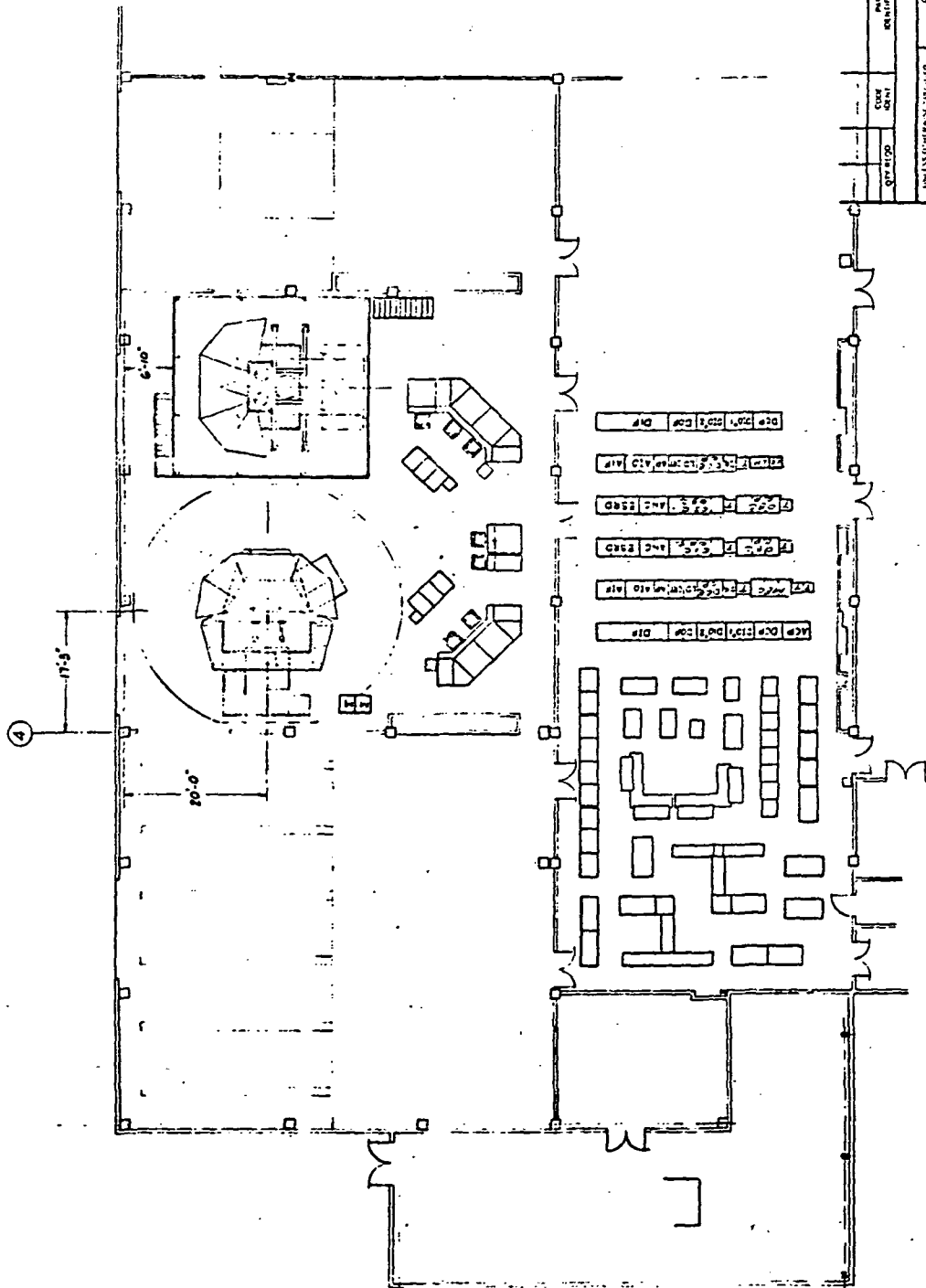
The Motion Based Simulator and Fixed Based Simulator are both located in the high bay area of the facility which has a 30'-9" high clear ceiling and a concrete floor adequately reinforced to accommodate the relatively high static and dynamic loading imposed by the motion system.

The SMS arrangement as shown on Figure 2.3.1-2 allows approximately 35 ft. of width for installation of the visual system on the motion platform. The visual system envisioned is comparable in size to that of the ASUPT which required 32 ft. in width during failed motion modes.

The remaining 28 ft. of width in the high bay area is devoted to the FBCS raised platform.



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| <u>SMS<br/>SYSTEM</u>                       | <u>FUNCTION</u>                                 | <u>MBCS<br/>EQUIPMENT<br/>BAYS</u> | <u>FBCS<br/>EQUIPMENT<br/>BAYS</u> |
|---|---|------------------------------------|------------------------------------|
| MOTION                                      | MOTION ELECTRONICS                              | 1                                  | -                                  |
| MOTION                                      | TILT ELECTRONICS                                | 1                                  | -                                  |
| DCE (& IOS CRT)                             | PDP 11/45 MINI COMPUTER                         | 2                                  | 2                                  |
| DCE   | DEC WRITER TERMINAL                             | 1                                  | 1                                  |
| DCE   | DCE LINE DRIVERS & SINE<br>CONVERTER            | 1                                  | 1                                  |
| DCE   | DIGITAL I/O NO. 1                               | 2                                  | 2                                  |
| DCE   | DIGITAL I/O NO. 2                               | 2                                  | 2                                  |
| DCE   | DIGITAL INPUT INTERFACE &<br>SELF TEST          | 5                                  | 5                                  |
| DCE   | DIGITAL OUTPUT INTERFACE<br>& SELF TEST         | 3                                  | 3                                  |
| DCE   | ANALOG POWER                                    | 1                                  | 1                                  |
| DCE   | ANALOG I/O                                      | 2                                  | 2                                  |
| DCE   | ANALOG INTERFACE                                | 2                                  | 2                                  |
| DCE   | ESRD  | 3                                  | 3                                  |
| ANCILLARY<br>EQUIPMENT                      | AURAL CUE, COMMUNICATIONS<br>INSTRUMENT DRIVERS | 2                                  | 2                                  |
| ANCILLARY<br>EQUIPMENT                      | AC POWER  | 2                                  | *                                  |
| ANCILLARY<br>EQUIPMENT                      | DC POWER  | 2                                  | 2                                  |
| IOS CRT SYSTEM                              | IOS CRT ELECTRONICS                             | 1                                  | 1                                  |
| DP&S MCM                                    | PDP 11/45 MINICOMPUTERS                         | 3                                  | 3                                  |
| MAIN ENGINE                                 | PDP11/45 MINICOMPUTERS                          | 3                                  | *                                  |
| DP&S  | DEC WRITER TERMINALS                            | 4                                  | 1                                  |
| DP&S  | COMPUTER INTERFACE CONTROLLER                   | 2                                  | 2                                  |
| DP&S  | API01 COMPUTERS AND INTERFACE<br>HARDWARE       | 2                                  | 2                                  |
| MINI<br>COMPUTER<br>PERIPHERAL<br>EQUIPMENT | LINE PRINTER LP11-JA                            | 1                                  | *                                  |
|   | CARD READER CR-11                               | 1                                  | *                                  |
|   | DISC SYSTEM RK-05                               | 1                                  | 1                                  |
|   | HIGH SPEED PAPER TAPE                           | **                                 | *                                  |
|   | DEC TAPE  | **                                 | *                                  |

\* SHARED BY MBCS AND FBCS  
 \*\* MOUNTED IN PDP11 CABINET

TABLE 2.3.1-1  
 SMS ELECTRONIC EQUIPMENT LIST

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## 2.3.2 Building 5 Modification Requirements

### 2.3.2.1 Architectural

Architectural modifications to the Building 5 Facility relate to local cable-trough filling and leveling as indicated in Figure 2.3.2-1 and a trench for hydraulic line installations as shown in Figure 3.2.9-15.

### 2.3.2.2 Electrical Modifications

No extensive electrical modifications to the Building 5 facility are required.

However, fused disconnect switches must be installed or otherwise provided for 277/480 volt and 120/208 volt 60 Hz three phase power and for 115 volt 400 Hz power as indicated in Section 2.3.3 below. Electric power cables will be required to the SMS Hydraulic Equipment room, to the AC power cabinet, and to the Simulation Computer Complex (GFE) as shown in Figure 2.3.2-2.

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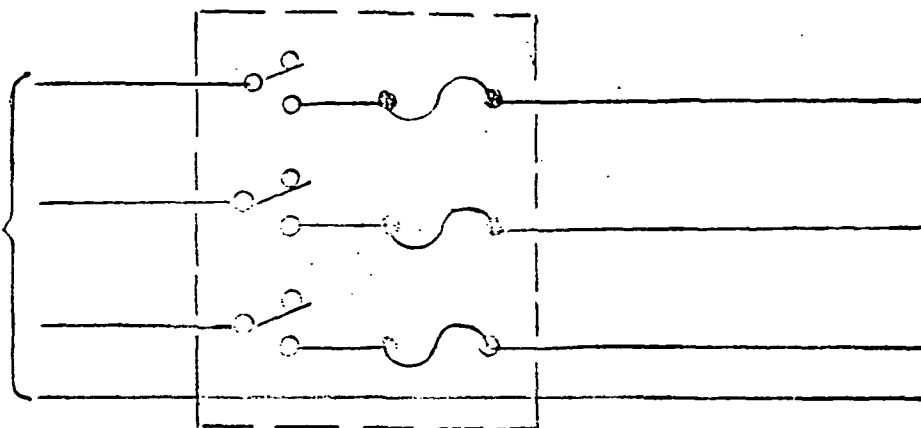
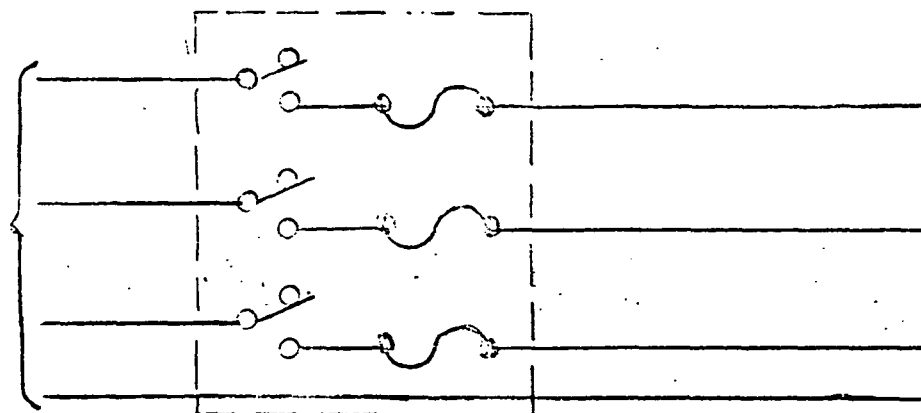
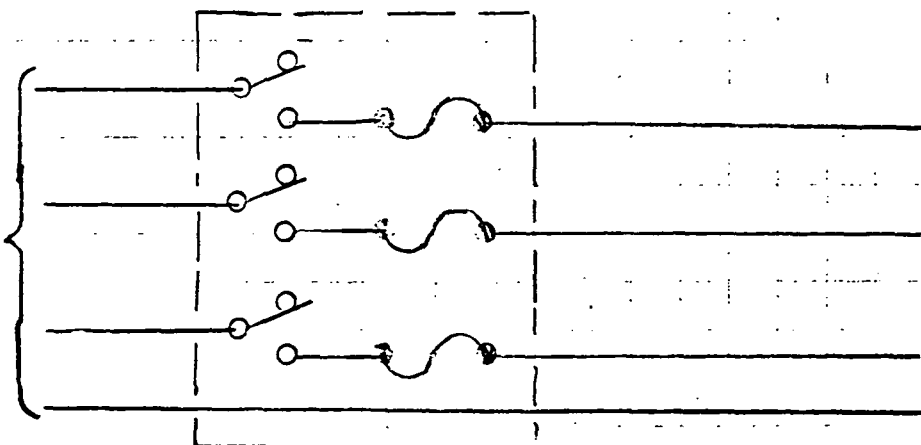
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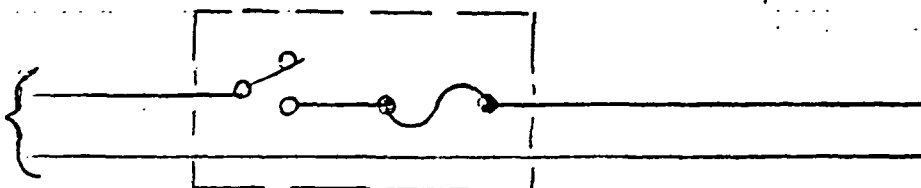
REV.

BINGHAMTON, NEW YORK

REP. NO.

277/480V  
60 HzTO  
SMS  
MOTION  
SYSTEM  
400 AMPERES  
PER PHASE  
PEAK  
90 AMPERES PER  
PHASE NOMINAL120/208V  
60 HzTO  
SMS  
920 AMPERES  
PER PHASE120/208V  
60 HzTO  
SMS  
SCC  
700 AMPERES  
PER PHASE

115V/400 Hz

TO  
SMS  
10 AMPERES

43&lt;

FIGURE 2.3.2-2

### 2.3.3 Electrical Power Requirements

The SMS will be designed to operate from NASA furnished power sources having the following characteristics:

- a) Three phase, Y connected, 4 wire 277/480 VAC, 60HZ power.
- b) Three phase, Y connected, 4 wire, 120/208 VAC, 60HZ power.
- c) Single phase 115V AC, 400HZ power.

#### 2.3.3.1 277/480V Power

The following equipment will be powered by 277/480V, three phase, 60-hertz power.

|                      |      | <u>KVA</u>     |                       |
|----------------------|------|----------------|-----------------------|
|                      |      | <u>Start</u>   | <u>Normal Running</u> |
| Main Hyd. Pump #1    | 75HP | 109            | 30                    |
| Main Hyd. Pump #2    | 75HP | 109            | 30                    |
| Control Loading Pump | 10HP | 64             | 9                     |
| Boost Pump           | 5HP  | 34             | 4                     |
|                      |      | <u>316 Kva</u> | <u>73 Kva</u>         |

#### 2.3.3.2 120/208V Power

The SMS will be designed to operate from a 120/208 volt ( $\pm 10\%$ ), three-phase, four-wire, 60-hertz ( $\pm 5\%$ ) primary power source. The power factor will be 85% and line current unbalance will not exceed  $\pm 7.5\%$  of the average line current.

The facility-supplied main fused disconnect switch will control all power to the simulator. Tripping or throwing the shunt-trip breaker will also shut off all power to the simulator equipment.

All fused wall disconnects and associated cabling up to the simulator equipment will be supplied by NASA.

120/208 Volt Power requirements for the SMS are summarized below:

|                              | <u>MBCS</u><br><u>Volt Amperes</u> | <u>FBCS</u><br><u>Volt Amperes</u> |
|------------------------------|------------------------------------|------------------------------------|
| Crew Station                 | 6,000                              | 8,000                              |
| Instructor Operator Station  | 4,000                              | 6,000                              |
| Ancillary Equipment          | 2,000                              | 2,000                              |
| On-Board Computers           | 11,600                             | 12,600                             |
| Computer Complex (GFP)       | 250,000                            | Shared                             |
| Digital Conversion Equipment | 21,774                             | 19,424                             |
| Visual Systems               | 108,000                            | 144,000                            |
| Motion System Electronics    | 500                                | ----                               |

#### 2.3.3.2.1 Utility Power

Utility power will also be provided from the main power disconnect box and will be available while the remainder of the simulator power is off. This power will be used for trouble lights, reel type recoil lights, instructor station lights, utility power outlets, and the maintenance intercommunication system.

#### 2.3.3.3 400 HZ Power

The 115 volt, single phase 400 HZ power will be provided for the SMS.

Approximately 1100 volt amperes will be required. The power factor will be 85% or better.

#### 2.3.3.4 Power Transients Investigation

An investigation of AC power transients problems at the simulator site at JSC indicates that short duration line voltage transients occur quite often which have adverse effects on the computers associated with the CMS, LMS, and Skylab Simulators. Voltage drop transients of 10 percent are reported to initiate automatic shut-down of these computers. The DDP-224 computer memories, in particular, are reported to be very sensitive.

However, there is no reported evidence that these transients adversely affect the IEM 360 computer on the Skylab Simulator nor that they have caused problems in the simulators in areas other than the DDP-224's. Since the Shuttle Simulator will also incorporate a state-of-the-art computer system and simulator electronic equipment, it is highly probable that the SMS will remain operational under similar short duration power transient conditions.

Long duration power drops will be monitored by the simulator computer power fail-safe electronics and additional sensing and interlock equipment in the DCE, Power Distribution, and Motion System electronics, to insure that the simulator computer software programs are not lost and that the equipment is operationally fail-safe. 46<

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## 2.4 Software Components

The baseline software was divided into Malfunction Insertion, Flight Software, Applications Software, and System Software. Failure Insertion Concepts is generally applicable to all three of the other areas since this is the means of introducing off-nominal performance and is implemented by Systems Software inputs to the Application Software. Flight Software refers to the software developed for real world use. This includes the on-board computers for Guidance, Navigation and Control and the Main Engines and Display. System software includes the required simulator control systems, as well as the data management system. The Applications Software is divided into ten major systems by engineering discipline.

The following pictorial charts provide an overview of the systems and subsystems covered in this report and include paragraph numbers for quick reference.

In most cases, the operational on-board subsystems have either not been developed or selected for use in the shuttle. This has necessitated using existing aerospace subsystems as "like-items" for the baseline. In all conceptual designs, the requirements of the real world systems as expected on 12/31/72 are met.

The computer software requirements are summarized in pages 2.4-16 through 2.4-21. In order to maintain uniformity for all candidate computers, an instruction is equivalent in size to one computer word.

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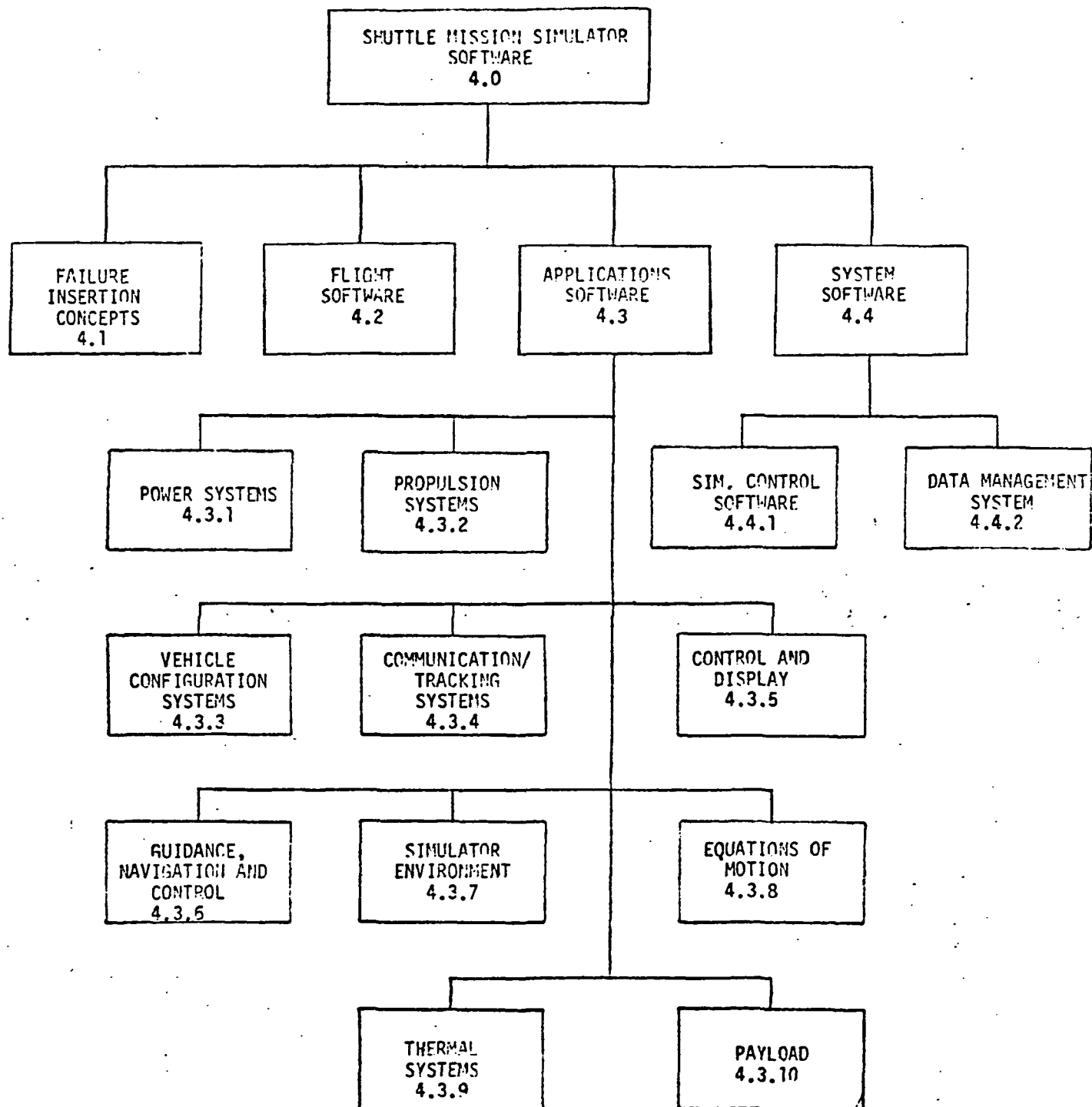
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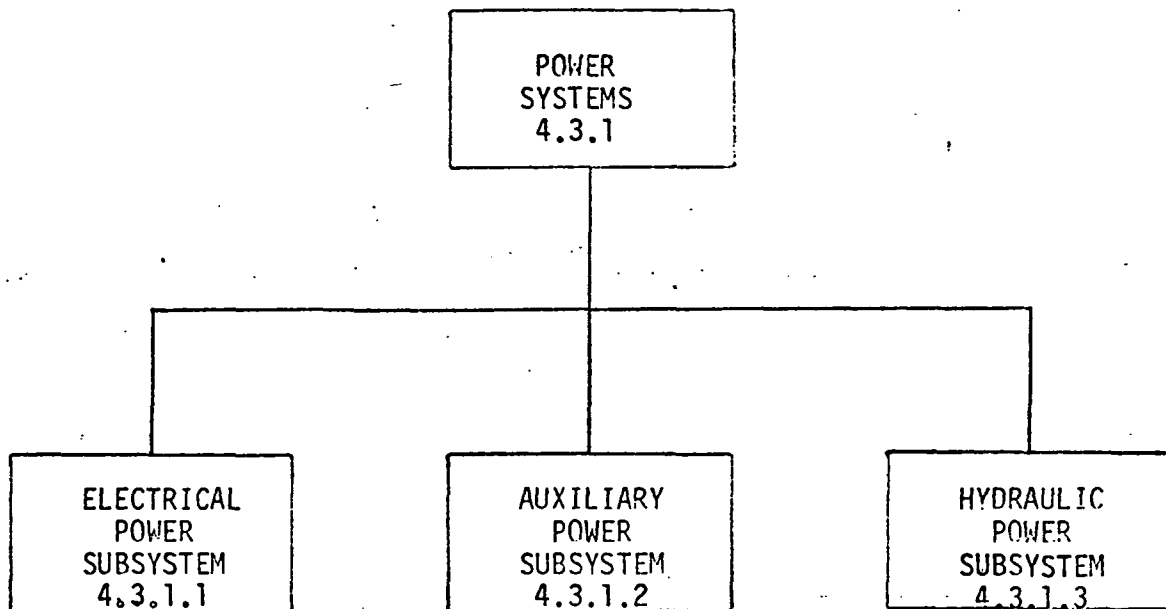
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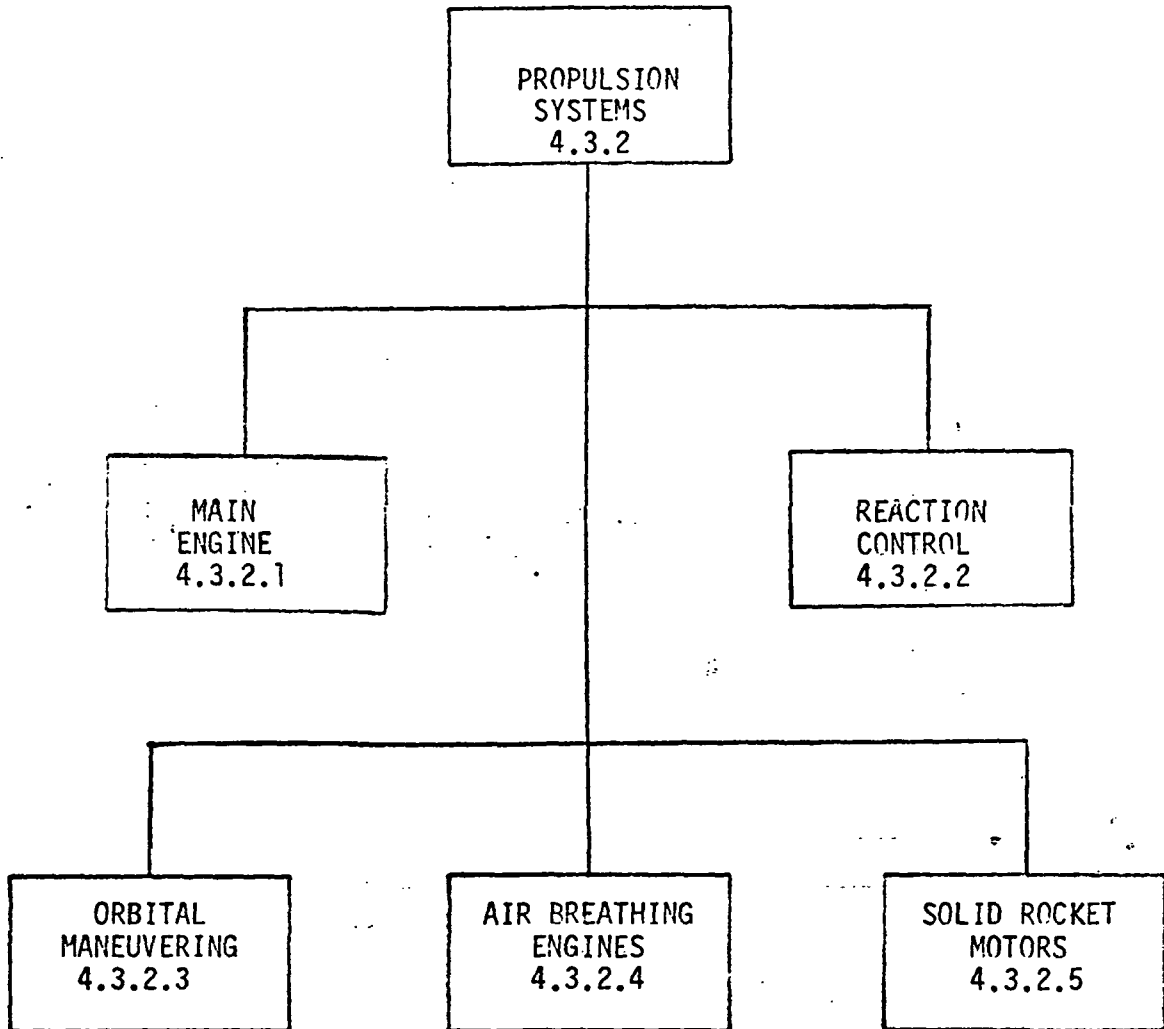
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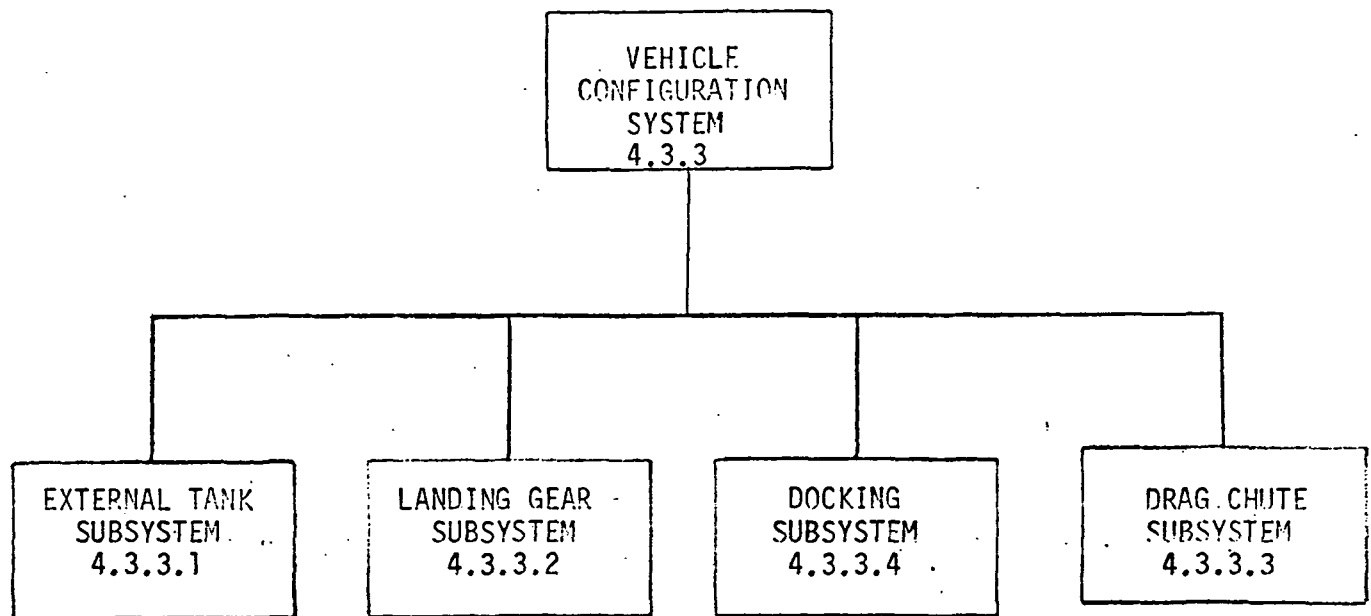
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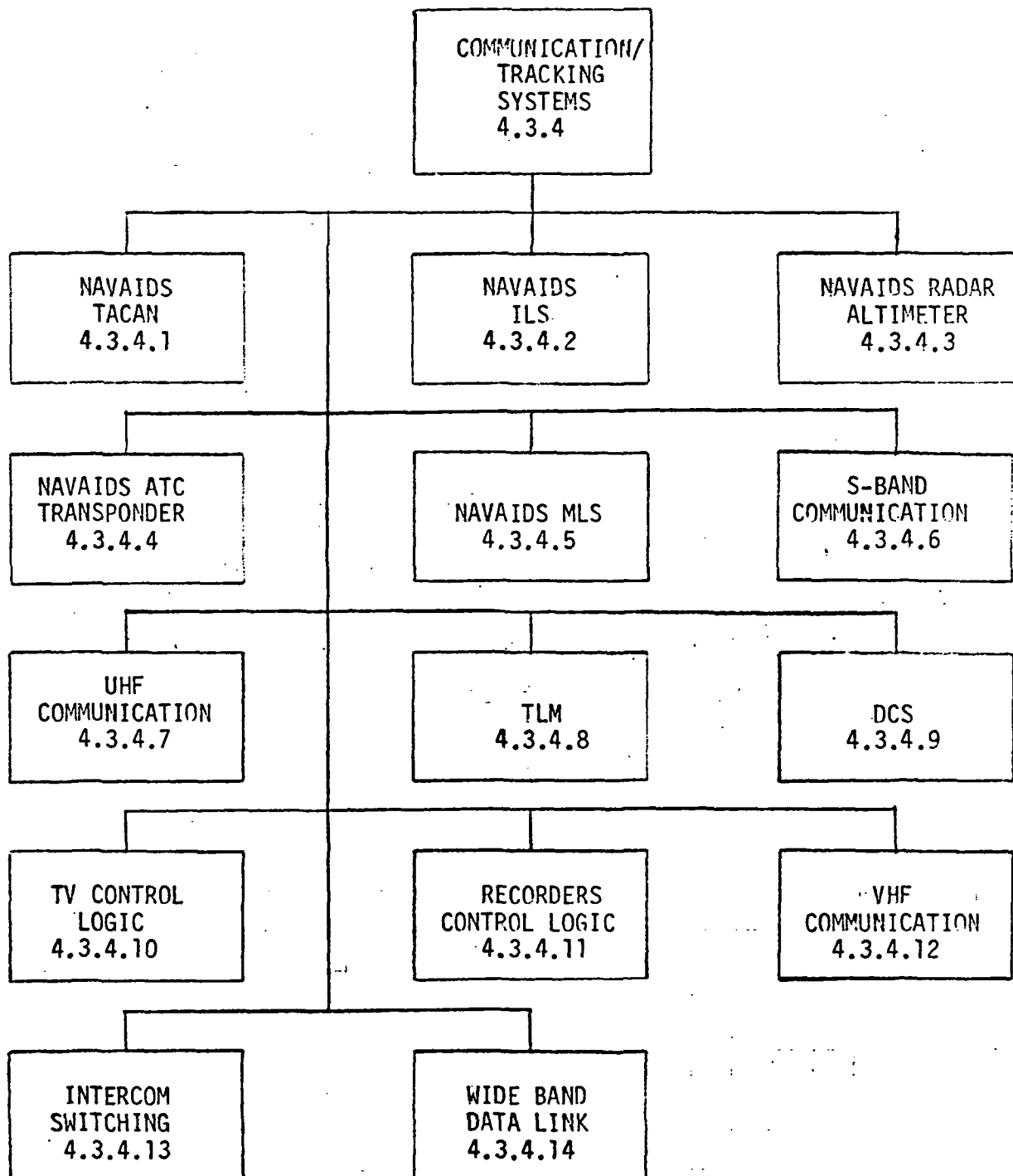
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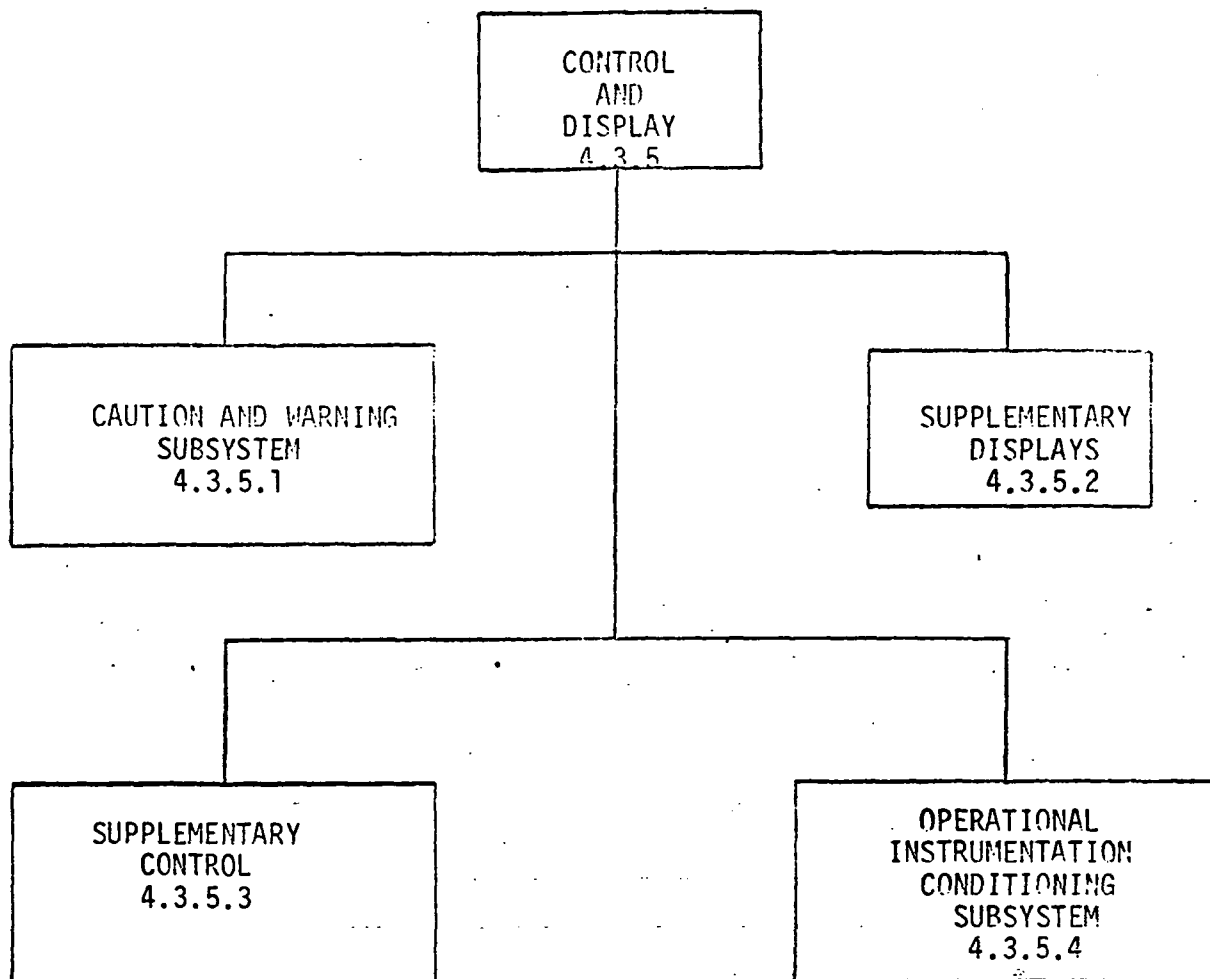
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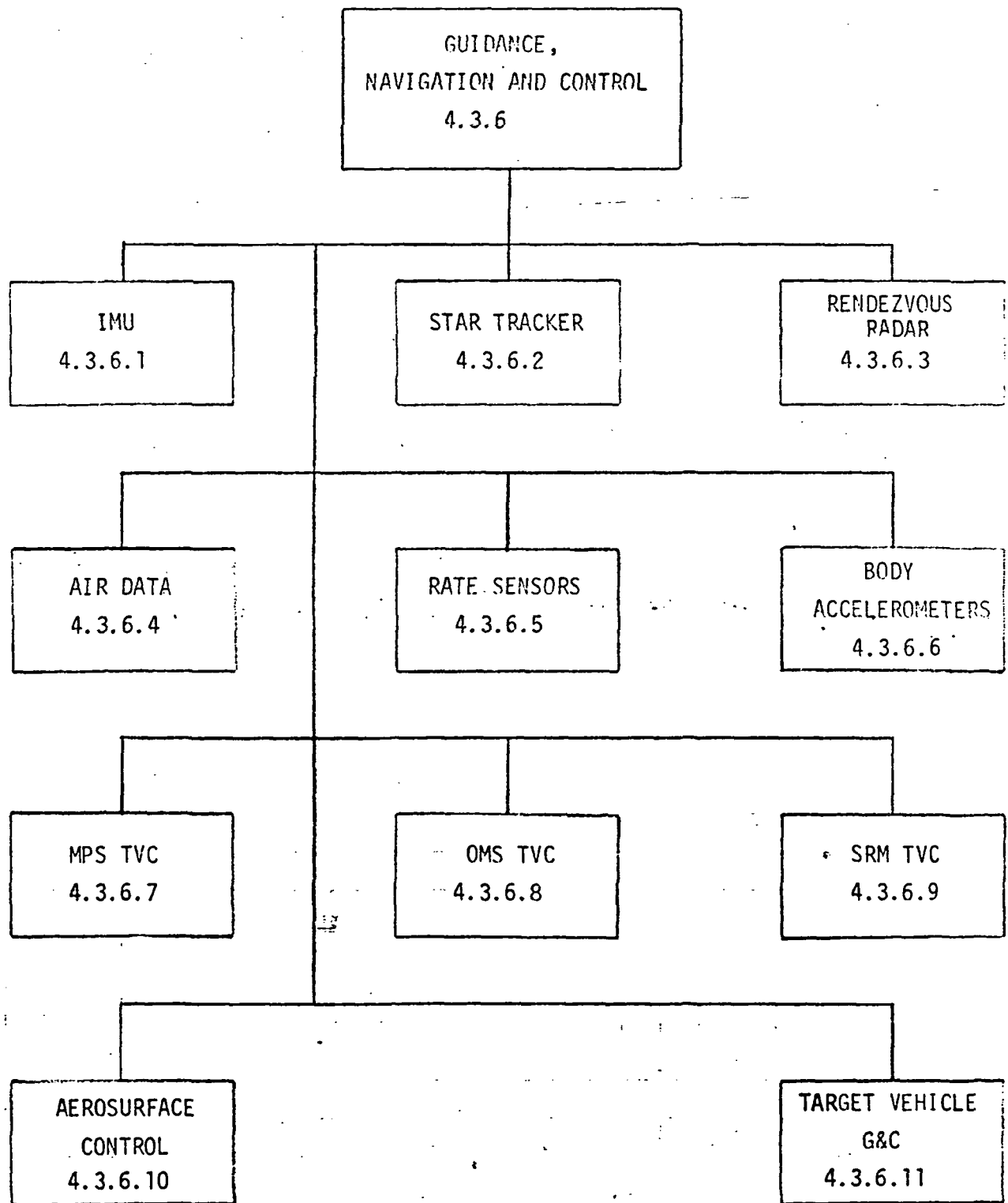
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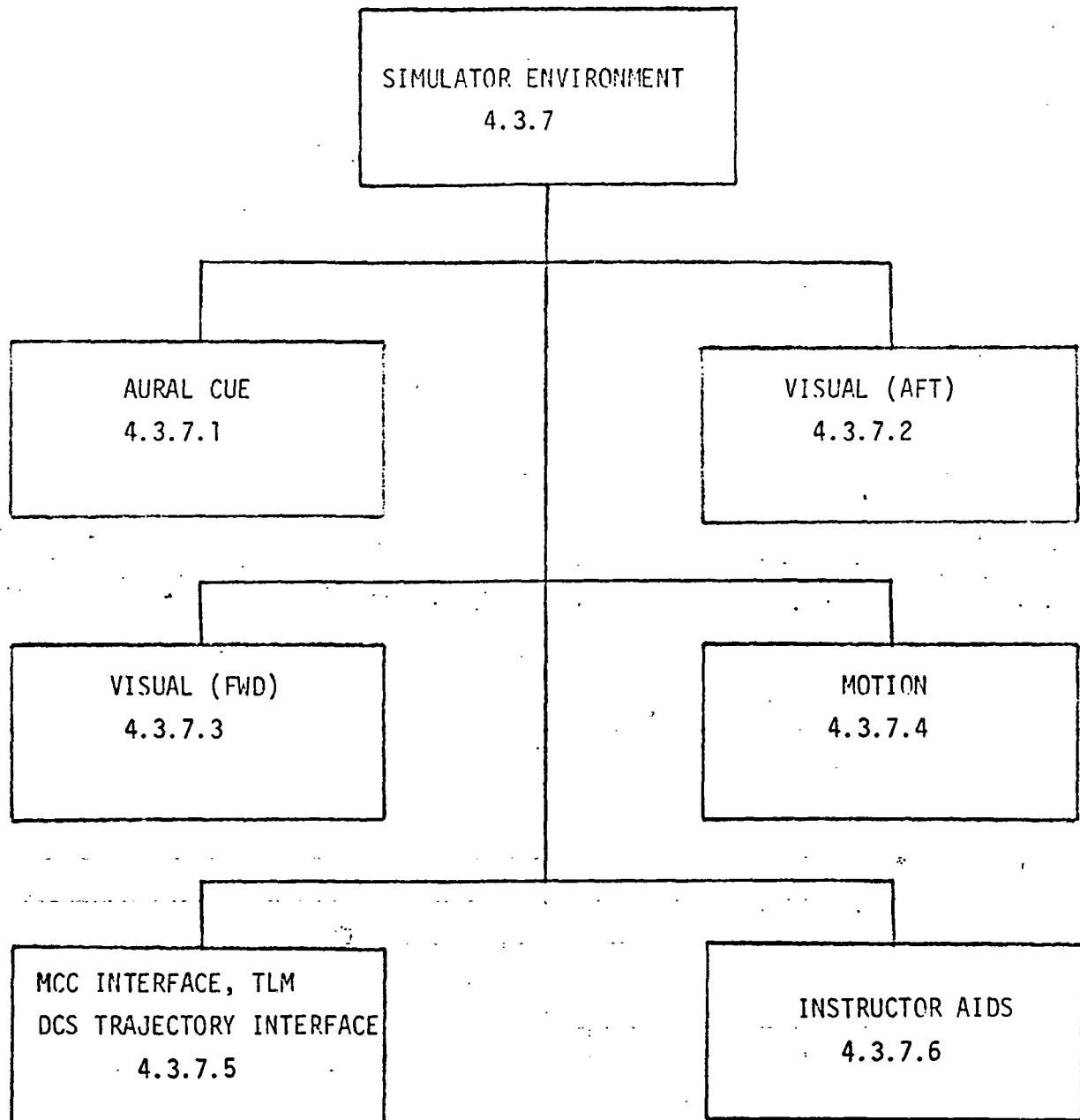
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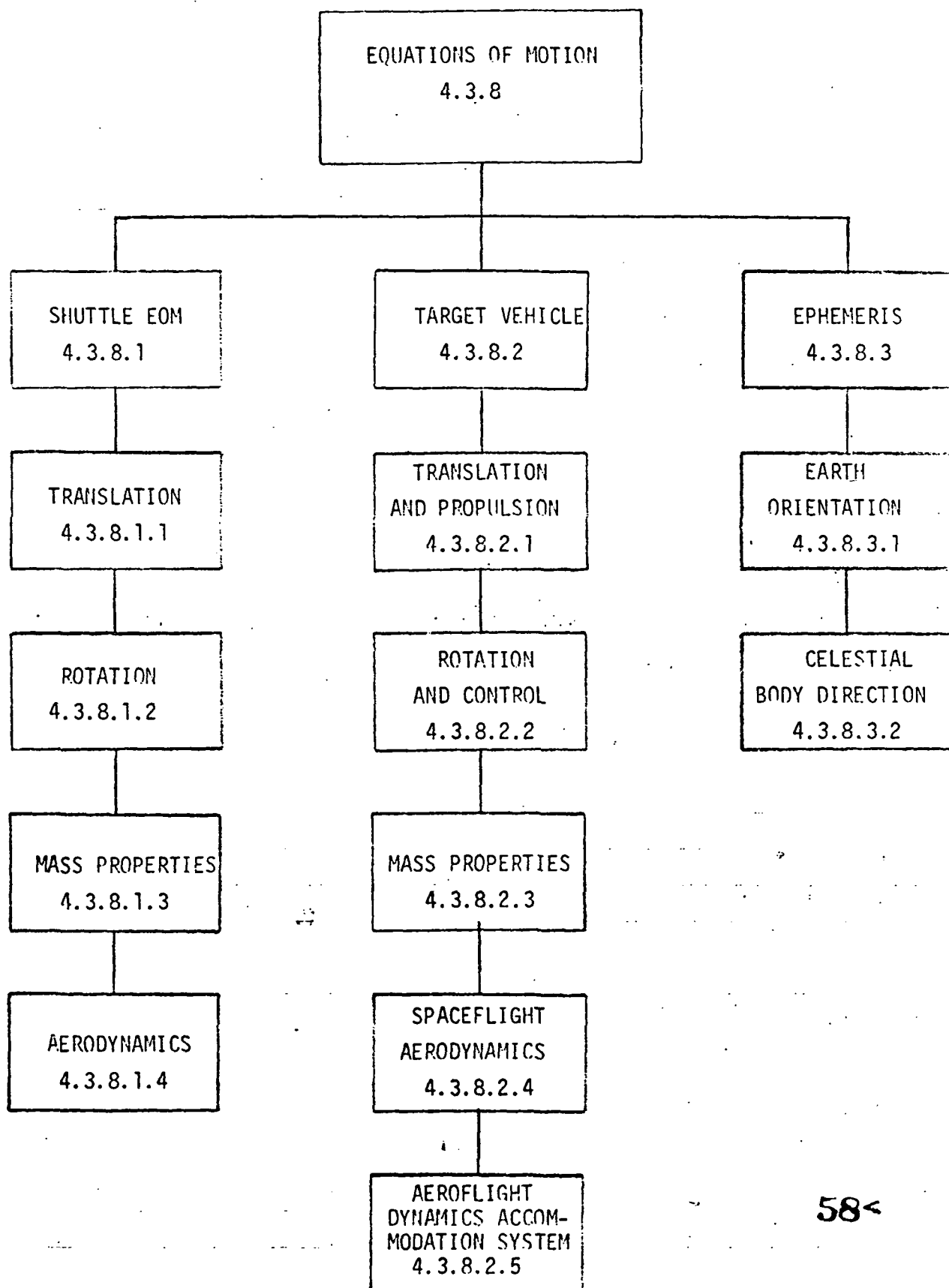
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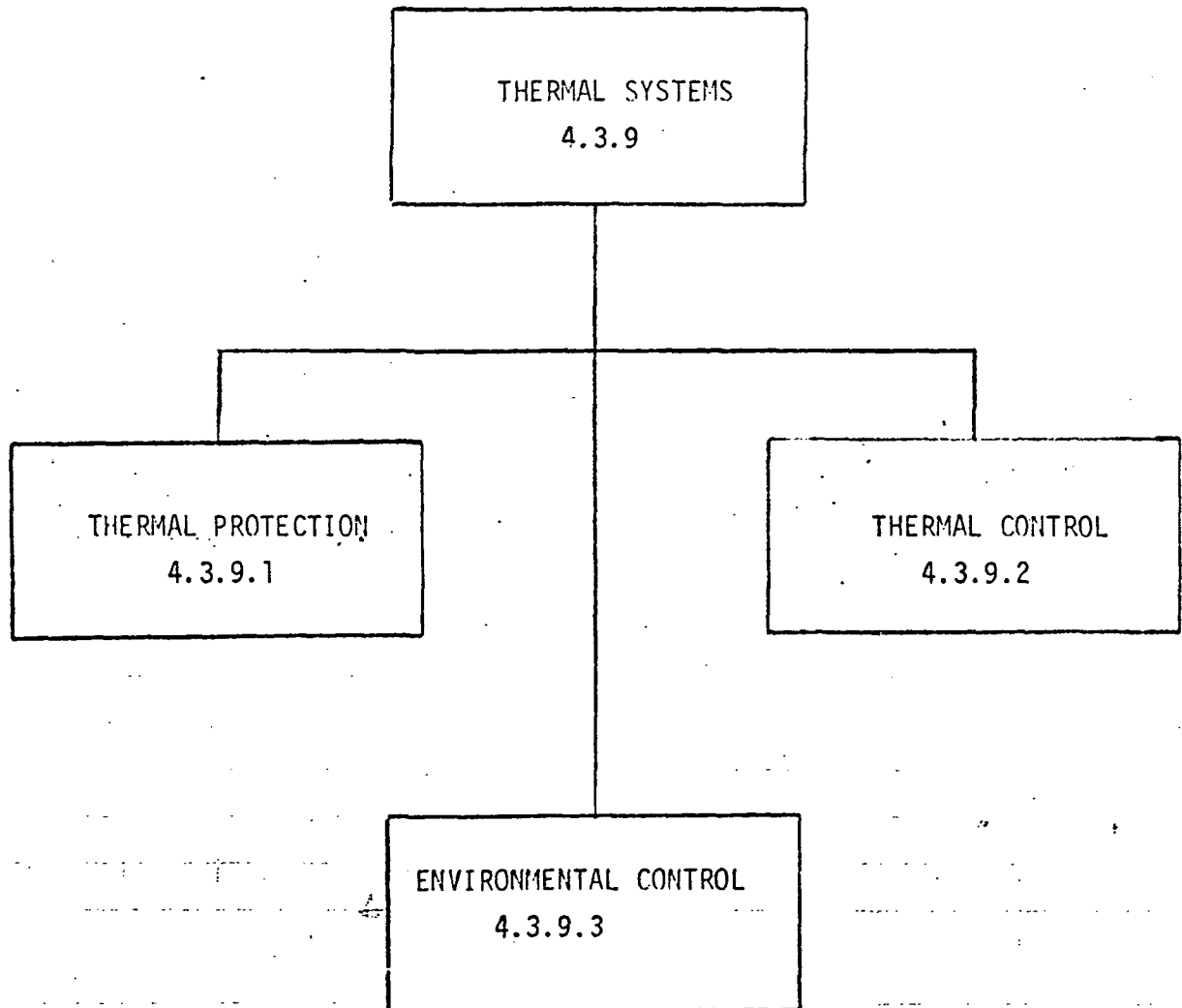
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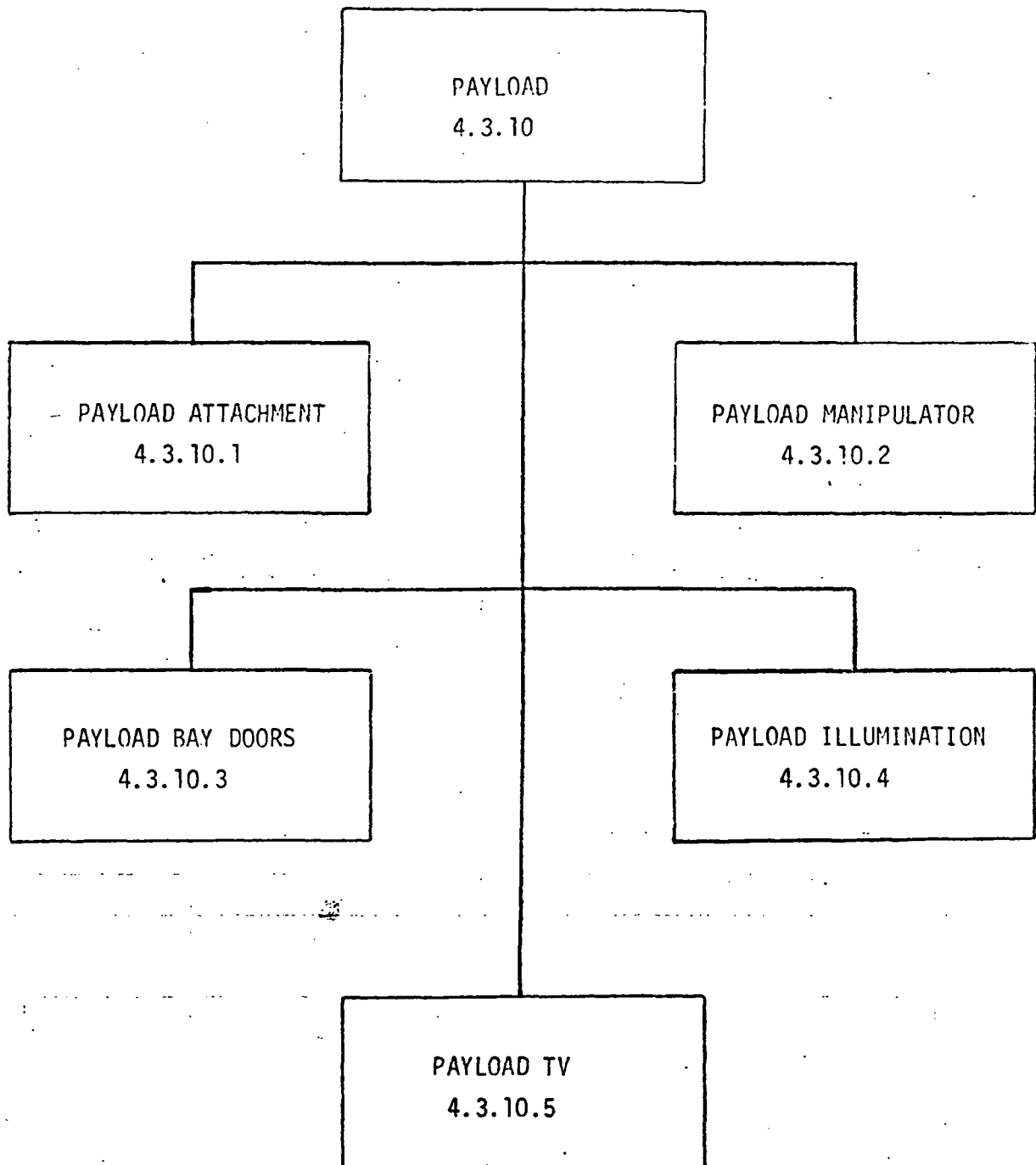
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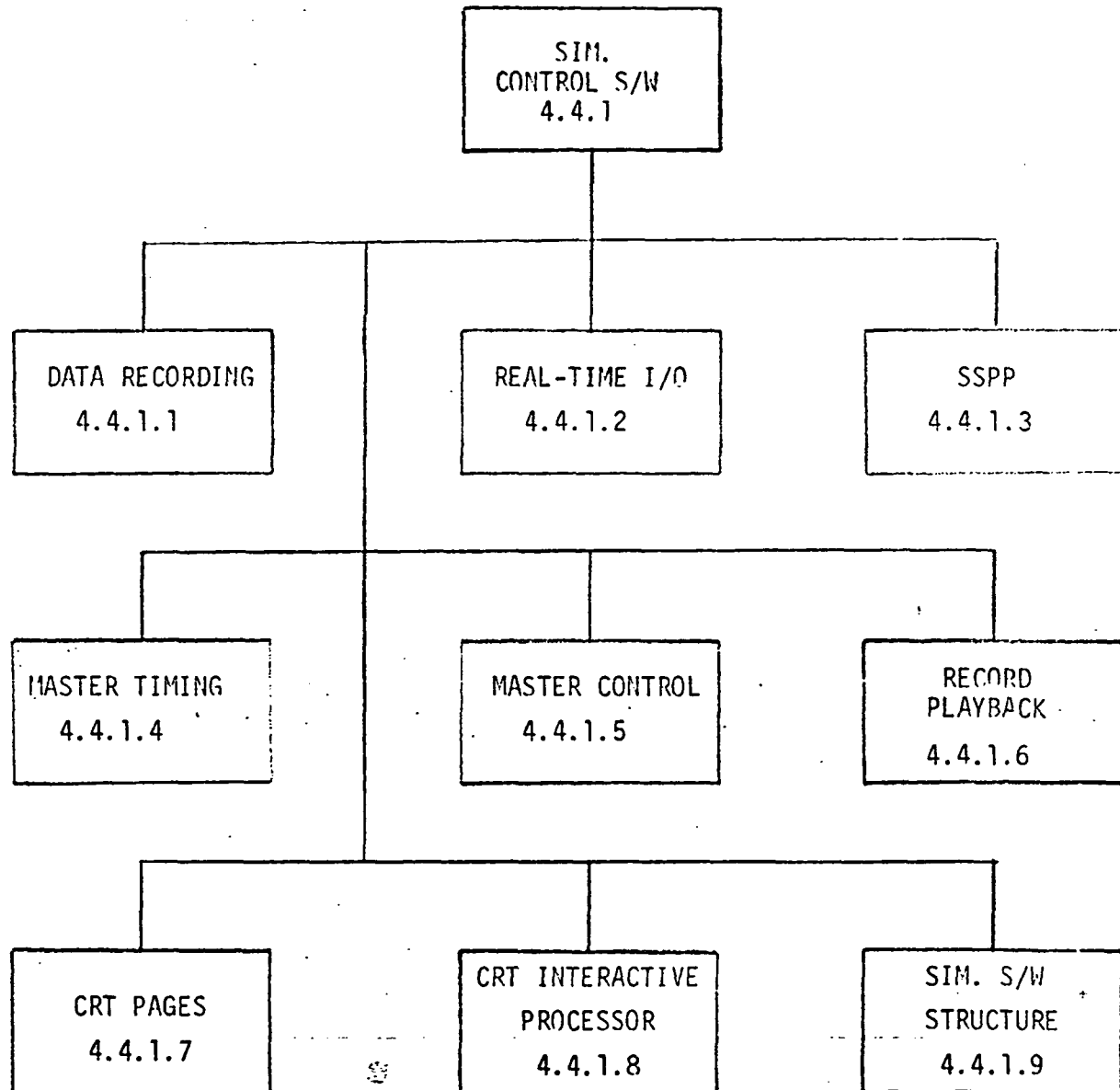
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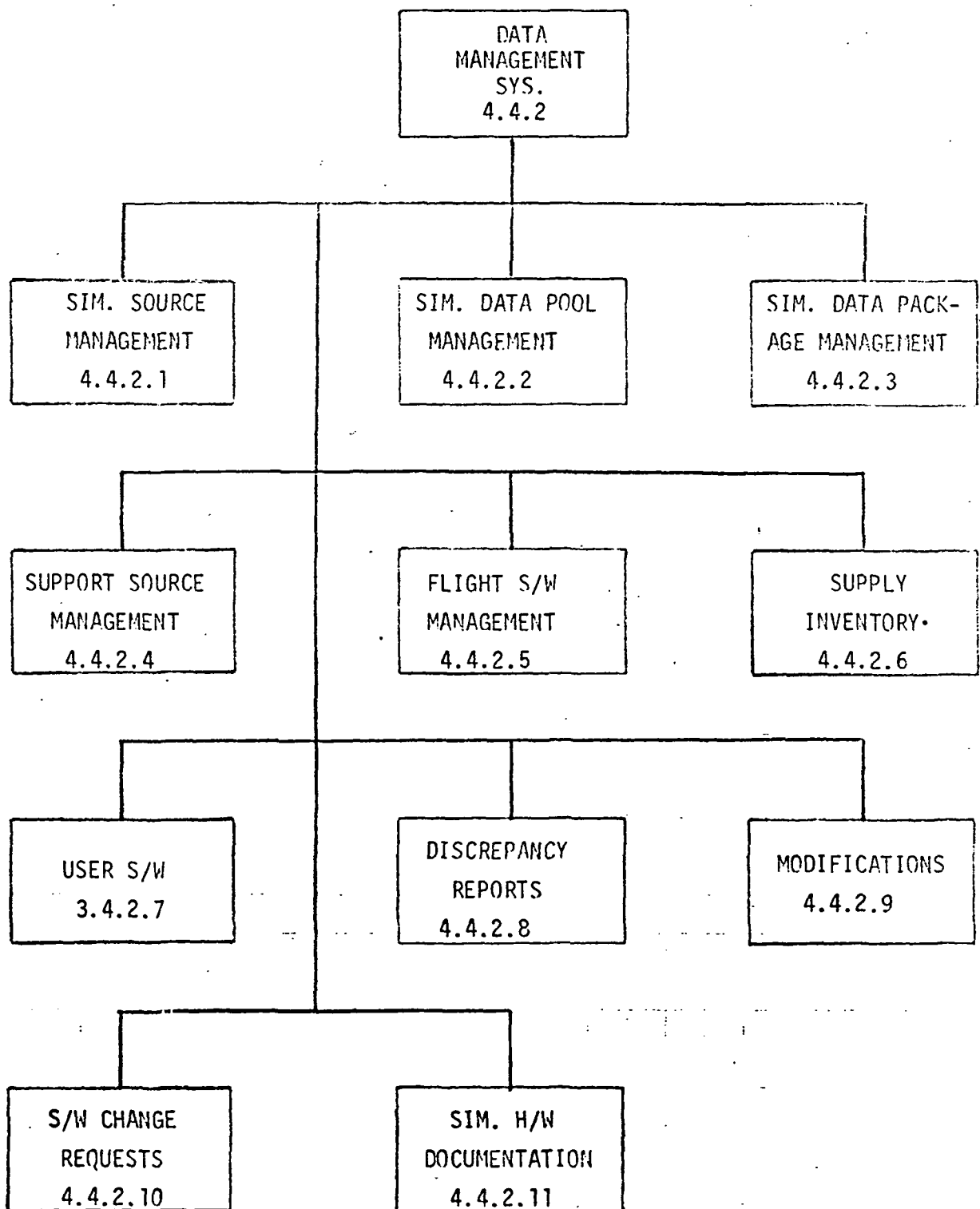
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|  |  |                     |                |           |              |           |                         |        |        |            |             |        |        |          |        |
|--|--|---------------------|----------------|-----------|--------------|-----------|-------------------------|--------|--------|------------|-------------|--------|--------|----------|--------|
| CNS COMPUTER LOADING OF 12/13/73 AT 14:53.12 |  |                     |                |           |              |           |                         |        |        |            |             |        |        |          |        |
| MOTION BASE STATION                          |  |                     |                |           |              |           |                         |        |        |            |             |        |        |          |        |
| PAGE 1                                       |  |                     |                |           |              |           |                         |        |        |            |             |        |        |          |        |
| SYSTEM SUBSYSTEM                             |  | NUMBER OF EQUATIONS | NUM. OF INST'S | DATA BASE | PROG. BUFFER | ITER RATE | INSTRUCTIONS PER SECOND |        |        | BY MISSION | PHASE ENTRY | ORBIT  | BOOST  | APP/LAND | FERRY  |
| WATER LIBRARY                                |  | 25*                 | 25             | 3         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| LF1(1)                                       |  | 50*                 | 50             | 7         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| LF1(2)                                       |  | 100*                | 100            | 14        | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| LF1(3)                                       |  | 36*                 | 36             | 5         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| SCOT   |  | 43*                 | 43             | 6         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| TRIC   |  | 58*                 | 58             | 8         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| ATRIC  |  | 100*                | 100            | 14        | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| MATRIX MULT                                  |  | 100*                | 100            | 14        | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| VECTOP NCOM                                  |  | 100*                | 100            | 14        | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| VECTOP ROTATION                              |  | 50*                 | 50             | 7         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| PANCOM NO.                                   |  | 50*                 | 50             | 7         | 0            | 1         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| SYSTEM TOTAL                                 |  |                     | 612            | 85        |              |           |                         |        |        |            |             |        |        |          |        |
| DRIVER SYSTEMS                               |  | 2510                | 12675          | 5020      | 0            | 4         | 101400                  | 101400 | 101400 | 101400     | 101400      | 101400 | 101400 | 101400   | 101400 |
| ENC  |  | 500                 | 2524           | 2000      | 0            | 4         | 40384                   | 40384  | 40384  | 40384      | 40384       | 40384  | 40384  | 40384    | 40384  |
| APL  |  | 150                 | 757            | 525       | 0            | 4         | 10598                   | 10598  | 10598  | 10598      | 10598       | 10598  | 10598  | 10598    | 10598  |
| SYSTEM TOTAL                                 |  |                     | 15956          | 7545      |              |           | 152382                  | 152382 | 152382 | 152382     | 152382      | 152382 | 152382 | 152382   | 152382 |
| PROPULSION SYSTEMS                           |  | 1200                | 6059           | 2400      | 0            | 4         | 48472                   | 48472  | 48472  | 48472      | 48472       | 48472  | 48472  | 48472    | 48472  |
| SSME (FUNCTIONAL)                            |  | 1200                | 6059           | 1800      | 0            | 2         | 18177                   | 18177  | 18177  | 18177      | 18177       | 18177  | 18177  | 18177    | 18177  |
| SSME (FUNCTIONAL)                            |  | 195                 | 1181           | 153       | 0            | 4         | 4724                    | 4724   | 4724   | 4724       | 4724        | 4724   | 4724   | 4724     | 4724   |
| PCS  |  | 20                  | 121            | 100       | 0            | 10        | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| PCS  |  | 70                  | 424            | 700       | 0            | 20        | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| PCS  |  | 200                 | 1211           | 300       | 0            | 4         | 7266                    | 7266   | 7266   | 7266       | 7266        | 7266   | 7266   | 7266     | 7266   |
| PCS  |  | 120                 | 727            | 180       | 0            | 10        | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| PCS  |  | 650                 | 3238           | 2600      | 0            | 5         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| ARCS   |  | 100                 | 605            | 800       | 600          | 10        | 0                       | 12100  | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| SYSTEM TOTAL                                 |  |                     | 20325          | 9075      |              |           | 76634                   | 90739  | 180394 | 180394     | 180394      | 180394 | 180394 | 180394   | 180394 |
| VEHICLE CONFIG. SVS.                         |  | 30                  | 151            | 30        | 0            | 10        | 1510                    | 1510   | 1510   | 1510       | 1510        | 1510   | 1510   | 1510     | 1510   |
| EXT. TANK SEP. LOGIC                         |  | 60                  | 363            | 60        | 0            | 20        | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| LANDING GEAR                                 |  | 0                   | 0              | 0         | 0            | 0         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| LOCKING                                      |  | 18                  | 109            | 18        | 0            | 5         | 0                       | 0      | 0      | 0          | 0           | 0      | 0      | 0        | 0      |
| PARACHUTE                                    |  |                     | 623            | 108       |              |           | 1510                    | 1510   | 1510   | 1510       | 1510        | 1510   | 1510   | 1510     | 1510   |
| SYSTEM TOTAL                                 |  |                     |                |           |              |           |                         |        |        |            |             |        |        |          |        |

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PAGE 2

MOTION BASE STATION

12/13/73 AT 14:53.12

NAME COMPUTER LOADING OF

| SYSTEM              | NUMBER OF EQUATIONS | NUM. OF INST.'S | DATA# | PROG. BASE | ITER | INSTRUCTIONS PER SECOND | BOOST  | ORBIT  | ENTRY  | APP/LAND | FERRY  |
|---------------------|---------------------|-----------------|-------|------------|------|-------------------------|--------|--------|--------|----------|--------|
| SCPM. /TRACKING     | 200                 | 1211            | 10600 | 10000      | 10   | 36330                   | 36330  | 36330  | 36330  | 36330    | 36330  |
| TACAN               |                     |                 |       |            |      |                         |        |        |        |          |        |
| MATH SUBROUTINES    |                     |                 |       |            |      |                         |        |        |        |          |        |
| TPIC                |                     |                 |       |            |      | 3870                    | 3870   | 3870   | 3870   | 3870     | 3870   |
| ATPIC               |                     |                 |       |            |      | 3480                    | 3480   | 3480   | 3480   | 3480     | 3480   |
| HIS/PLS             | 200                 | 1211            | 400   | 0          | 10   | 3027                    | 3027   | 3027   | 3027   | 24220    | 24220  |
| MATH SUBROUTINES    |                     |                 |       |            |      |                         |        |        |        |          |        |
| TPIC                |                     |                 |       |            |      | 0                       | 0      | 0      | 0      | 3870     | 3870   |
| ATPIC               |                     |                 |       |            |      | 0                       | 0      | 0      | 0      | 3480     | 3480   |
| SORT                |                     |                 |       |            |      | 0                       | 0      | 0      | 360    | 2520     | 2520   |
| RACAP ALTIMETER     | 120                 | 727             | 5240  | 5000       | 10   | 1454                    | 1454   | 1454   | 1454   | 14540    | 14540  |
| MATH SUBROUTINES    |                     |                 |       |            |      |                         |        |        |        |          |        |
| LF1121              |                     |                 |       |            |      | 0                       | 0      | 0      | 0      | 1000     | 1000   |
| ATC TRANSDUCER      | 10                  | 60              | 20    | 0          | 1    | 2524                    | 2524   | 2524   | 2524   | 2524     | 2524   |
| CAPAC. FORM.        | 125                 | 631             | 250   | 0          | 2    | 2524                    | 2524   | 2524   | 2524   | 2524     | 2524   |
| UPF FORM.           | 125                 | 631             | 250   | 0          | 2    | 2524                    | 2524   | 2524   | 2524   | 2524     | 2524   |
| TELEMETRY LOGIC     | 240                 | 969             | 3980  | 3500       | 2    | 3876                    | 3876   | 3876   | 3876   | 3876     | 3876   |
| PVS LN              | 500                 | 2019            | 500   | 0          | 2    | 4038                    | 4038   | 4038   | 4038   | 4038     | 4038   |
| PVS HT              | 600                 | 2423            | 600   | 0          | 10   | 24230                   | 24230  | 24230  | 24230  | 24230    | 24230  |
| TV CONTROL LOGIC    | 125                 | 631             | 125   | 0          | 2    | 1262                    | 1262   | 1262   | 1262   | 1262     | 1262   |
| REFERENCE CONTROL   | 24                  | 121             | 40    | 0          | 5    | 1210                    | 1210   | 1210   | 1210   | 1210     | 1210   |
| VHF FORM.           | 125                 | 757             | 250   | 0          | 2    | 3028                    | 3028   | 3028   | 3028   | 3028     | 3028   |
| INTERCOM SWITCHING  | 125                 | 631             | 250   | 0          | 2    | 2524                    | 2524   | 2524   | 2524   | 2524     | 2524   |
| ARTERIAL PATTERNS   | 125                 | 631             | 2125  | 2000       | 2    | 1262                    | 1262   | 1262   | 1262   | 1262     | 1262   |
| BINGHAM DATA LINK   | 10                  | 40              | 10    | 0          | 5    | 200                     | 200    | 200    | 200    | 200      | 200    |
| SYSTEM TOTAL        |                     | 12693           | 24668 |            |      | 94839                   | 94839  | 94839  | 95199  | 139988   | 110578 |
| CONTROL & DISPLAY   |                     |                 |       |            |      |                         |        |        |        |          |        |
| CAN                 | 600                 | 4241            | 2400  | 0          | 2    | 33928                   | 33928  | 33928  | 33928  | 33928    | 33928  |
| SYSTEM TOTAL        |                     | 4241            | 2400  |            |      | 33928                   | 33928  | 33928  | 33928  | 33928    | 33928  |
| GUIP/NAV/CONTROL    |                     |                 |       |            |      |                         |        |        |        |          |        |
| TUL                 | 1070*               | 1070            | 160   | 0          | 20   | 117700                  | 117700 | 117700 | 117700 | 117700   | 117700 |
| TUL                 | 285*                | 285             | 42    | 0          | 10   | 15675                   | 15675  | 15675  | 15675  | 15675    | 15675  |
| TUL                 | 183*                | 183             | 27    | 0          | 5    | 5032                    | 5032   | 5032   | 5032   | 5032     | 5032   |
| TUL                 | 705*                | 705             | 105   | 0          | 2    | 7755                    | 7755   | 7755   | 7755   | 7755     | 7755   |
| STAP TRACKER        | 240                 | 1454            | 1320  | 0          | 20   | 15994                   | 15994  | 15994  | 15994  | 15994    | 15994  |
| EPP/PLZUS RADAR     | 150                 | 908             | 450   | 0          | 5    | 1362                    | 1362   | 1362   | 1362   | 1362     | 1362   |
| AIR DATA COMPUTER   | 100                 | 605             | 350   | 0          | 10   | 21175                   | 21175  | 21175  | 21175  | 21175    | 21175  |
| RATE SENSORS        | 50                  | 302             | 225   | 0          | 20   | 27180                   | 27180  | 27180  | 27180  | 27180    | 27180  |
| P.A. ACCELEROMETERS | 40                  | 242             | 160   | 0          | 20   | 19360                   | 19360  | 19360  | 19360  | 19360    | 19360  |
| MPS TVC             | 375                 | 2272            | 1687  | 0          | 20   | 204480                  | 204480 | 204480 | 204480 | 204480   | 204480 |
| PVS TVC             | 300                 | 1817            | 750   | 0          | 20   | 10902                   | 10902  | 10902  | 10902  | 10902    | 10902  |
| SPM TVC             | 375                 | 2272            | 1125  | 0          | 20   | 136320                  | 136320 | 136320 | 136320 | 136320   | 136320 |
| AFROSLIDE, COMPT.   | 450                 | 2726            | 1350  | 0          | 20   | 163560                  | 163560 | 163560 | 163560 | 163560   | 163560 |
| TARGET VEH. GUIP.   | 40                  | 242             | 120   | 0          | 10   | 2420                    | 2420   | 2420   | 2420   | 2420     | 2420   |
| MATH SUBROUTINES    |                     |                 |       |            |      |                         |        |        |        |          |        |
| TRIG                |                     |                 |       |            |      | 0                       | 0      | 0      | 0      | 0        | 0      |
| ATRIC               |                     |                 |       |            |      | 0                       | 0      | 0      | 0      | 0        | 0      |
| SYSTEM TOTAL        |                     | 15083           | 7871  |            |      | 746495                  | 831743 | 554792 | 636869 | 497901   | 407051 |

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| MOTION BASE STATION   |  |                     |  |                 |  |           |  |                  |  |   |  | PAGE 3   |  |       |  |
|-----------------------|--|---------------------|--|-----------------|--|-----------|--|------------------|--|---|--|----------|--|-------|--|
| SYSTEM                |  | NUMBER OF EQUATIONS |  | NUM. OF INST.'S |  | DATA BASE |  | PRG. BUFFER RATE |  | ITER INSTRUCTIONS PER SECOND BY MISSION PHASE |  | APP/LAND |  | FERRY |  |
|                       |  |                     |  |                 |  |           |  |                  |  |   |  |          |  |       |  |
| SIMULATOR ENVIRONMENT |  |                     |  |                 |  |           |  |                  |  |   |  |          |  |       |  |
| ALPHA CUE             |  | 1300*               |  | 1300            |  | 319       |  | 125              |  | 5   |  | 2600     |  | 1625  |  |
| ALPHA CUE             |  | 1250*               |  | 1250            |  | 312       |  | 125              |  | 2   |  | 1000     |  | 625   |  |
| VISUAL (VEH. GEOM.)   |  | 6                   |  | 36              |  | 6         |  | 0                |  | 5   |  | 180      |  | 180   |  |
| VISUAL (EARTH SCENE)  |  | 50                  |  | 302             |  | 100       |  | 0                |  | 10  |  | 0        |  | 0     |  |
| VISUAL (MODEL A)      |  | 300                 |  | 1817            |  | 300       |  | 0                |  | 20  |  | 36340    |  | 0     |  |
| VISUAL (MODEL B)      |  | 300                 |  | 1817            |  | 300       |  | 0                |  | 10  |  | 0        |  | 0     |  |
| VISUAL (PEND. TARGET) |  | 20                  |  | 121             |  | 120       |  | 0                |  | 20  |  | 0        |  | 0     |  |
| VISUAL (STAGE/FIELD)  |  | 35                  |  | 212             |  | 105       |  | 0                |  | 20  |  | 0        |  | 14520 |  |
| VISUAL (CLOUD/FOG)    |  | 2                   |  | 12              |  | 2         |  | 0                |  | 2   |  | 0        |  | 12720 |  |
| MOTION BASE F1        |  | 11*                 |  | 11              |  | 1         |  | 0                |  | 20  |  | 220      |  | 24    |  |
| MOTION BASE MEC       |  | 493*                |  | 493             |  | 73        |  | 0                |  | 10  |  | 4930     |  | 220   |  |
| MATH SUBROUTINES      |  |                     |  |                 |  |           |  |                  |  |   |  |          |  | 3796  |  |
| SORT                  |  |                     |  |                 |  |           |  | 0                |  |   |  | 2160     |  | 4930  |  |
| MOTION BASE LN        |  | 35*                 |  | 35              |  | 5         |  | 0                |  | 5   |  | 175      |  | 2160  |  |
| MCC INTERFACE         |  | 250                 |  | 1514            |  | 250       |  | 0                |  | 20  |  | 30280    |  | 175   |  |
| SYSTEM TOTAL          |  |                     |  | 8920            |  | 1893      |  |                  |  |   |  | 77885    |  | 30280 |  |
|                       |  |                     |  |                 |  |           |  |                  |  |   |  | 126789   |  | 30280 |  |
|                       |  |                     |  |                 |  |           |  |                  |  |   |  | 70181    |  | 30280 |  |
|                       |  |                     |  |                 |  |           |  |                  |  |   |  | 55935    |  | 30280 |  |
|                       |  |                     |  |                 |  |           |  |                  |  |   |  | 79475    |  | 30280 |  |





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THE SINGER COMPANY  
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REV. A 12/21/73

BINGHAMTON, NEW YORK

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| MOTION BASE STATION  |                     |                 |           |                   |            |                         |                          |         |          | PAGE 5  |         |
|----------------------|---------------------|-----------------|-----------|-------------------|------------|-------------------------|--------------------------|---------|----------|---------|---------|
| SYSTEM               | NUMBER OF EQUATIONS | NUM. OF INST.'S | DATA BASE | PROG. BUFFER RATE | ITER. RATE | INSTRUCTIONS PER LAUNCH | PER. SEC. BY MISS. PHASE | ENTRY   | APP/LAND | FERRY   |         |
| FFMMENTS             | 40                  | 242             | 24        | 0                 | 10         | 484                     | 1452                     | 1452    | 1452     | 484     |         |
| MATH SUBROUTINES     |                     |                 |           |                   |            |                         |                          |         |          |         |         |
| TRIG                 |                     |                 |           |                   |            | 860                     | 860                      | 860     | 860      | 860     |         |
| VECTER ACMP          |                     |                 |           |                   |            | 0                       | 1000                     | 1000    | 1000     | 0       |         |
| SYSTEM TOTAL         |                     | 16397           | 22730     |                   |            | 163402                  | 693238                   | 666453  | 203776   | 204228  |         |
| THEOPAL SYSTEMS      |                     |                 |           |                   |            |                         |                          |         |          |         |         |
| COYGENICS            | 100                 | 706             | 200       | 0                 | 2          | 2824                    | 2824                     | 2824    | 2824     | 2824    |         |
| FCS LC               | 1346                | 9516            | 2422      | 0                 | 1          | 17128                   | 17128                    | 17128   | 17128    | 17128   |         |
| FCS MDN              | 1247                | 8816            | 1745      | 0                 | 2          | 24684                   | 24684                    | 24684   | 24684    | 24684   |         |
| FCS FI               | 670                 | 4736            | 670       | 0                 | 5          | 23680                   | 23680                    | 23680   | 23680    | 23680   |         |
| SYSTEM TOTAL         |                     | 23774           | 5037      |                   |            | 68316                   | 68316                    | 68316   | 68316    | 68316   |         |
| DAYLOCAC ACCOMMODATN |                     |                 |           |                   |            |                         |                          |         |          |         |         |
| SYSTEM TOTAL         |                     |                 |           |                   |            |                         |                          |         |          |         |         |
| SIMULATOR CONTROL    |                     |                 |           |                   |            |                         |                          |         |          |         |         |
| DATA RECORDING       | 750*                | 750             | 1712      | 1600              | 20         | 18000                   | 18000                    | 18000   | 18000    | 18000   |         |
| DEALTIM I/C          | 2200*               | 2200            | 1029      | 700               | 25         | 55000                   | 55000                    | 55000   | 55000    | 55000   |         |
| EXECUTIVE            | 400*                | 400             | 1059      | 1000              | 20         | 6400                    | 6400                     | 6400    | 6400     | 6400    |         |
| MASTER TIMING        | 1000*               | 1000            | 149       | 0                 | 20         | 20000                   | 20000                    | 20000   | 20000    | 20000   |         |
| MASTER CONTROL       | 4500*               | 4500            | 674       | 0                 | 20         | 13500                   | 13500                    | 13500   | 13500    | 13500   |         |
| OFFORN PLAYBACK      | 4500*               | 4500            | 1674      | 1000              | 5          | 67500                   | 67500                    | 67500   | 67500    | 67500   |         |
| COY                  | 5000*               | 5000            | 31749     | 31000             | 2          | 43000                   | 43000                    | 43000   | 43000    | 43000   |         |
| SYSTEM TOTAL         |                     | 18350           | 38046     |                   |            | 223400                  | 223400                   | 223400  | 223400   | 223400  |         |
| TOTALS               |                     | 136974          | 119438    |                   |            | 1620756                 | 2316884                  | 1717930 | 2112856  | 1601485 | 1437296 |

\* REPRESENTS AN INPUT NUMBER OF INSTRUCTIONS WHERE THE NUMBER OF EQUATIONS WAS UNAVAILABLE

\* ACA-STANDARD RATE (1 PER 8 SECONDS)

\* DATA PAGE TOTAL INCLUDES PROGRAM BUFFER

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BINGHAMTON, NEW YORK

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PAGE 1

SPS COMPUTER LOADING OF 12/13/73 AT 14:53.12      FIXED BASE STATION

| SYSTEM                | SUBSYSTEM            | NUMBER OF EQUATIONS | NUM. OF INST.'S | DATA BASE | PROG. BUFFER | ITER RATE | INSTRUCTIONS PER SECOND | MISSION PHASE | ORBIT  | ENTRY  | APPL/LAND | FERRY  |
|-----------------------|----------------------|---------------------|-----------------|-----------|--------------|-----------|-------------------------|---------------|--------|--------|-----------|--------|
| WATER SUPPLY          |                      |                     |                 |           |              |           |                         |               |        |        |           |        |
|                       | LE(11)               | 25*                 | 25              | 3         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | LE(12)               | 50*                 | 50              | 7         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | LE(13)               | 100*                | 100             | 14        | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | SCRT                 | 36*                 | 36              | 5         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | TDIC                 | 43*                 | 43              | 6         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | ATRIC                | 58*                 | 58              | 8         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | MATRIX MLY           | 100*                | 100             | 14        | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | VECTOP NORM          | 100*                | 100             | 14        | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | VECTOP PCTATION      | 50*                 | 50              | 7         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | DANFCO NO.           | 50*                 | 50              | 7         | 0            | 1         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | SYSTEM TOTAL         |                     | 612             | 85        |              |           |                         |               |        |        |           |        |
| POWER SYSTEMS         |                      |                     |                 |           |              |           |                         |               |        |        |           |        |
|                       | EPS                  | 2510                | 12675           | 5020      | 0            | 4         | 101400                  | 101400        | 101400 | 101400 | 101400    | 101400 |
|                       | APU                  | 500                 | 2524            | 2000      | 0            | 4         | 40384                   | 40384         | 40384  | 40384  | 40384     | 40384  |
|                       | HYDRAULICS           | 150                 | 757             | 525       | 0            | 4         | 10598                   | 10598         | 10598  | 10598  | 10598     | 10598  |
|                       | SYSTEM TOTAL         |                     | 15956           | 7545      |              |           | 152382                  | 152382        | 152382 | 152382 | 152382    | 152382 |
| DECOMPLISTION SYSTEMS |                      |                     |                 |           |              |           |                         |               |        |        |           |        |
|                       | SSWF (FUNCTIONAL)    | 1200                | 6059            | 2400      | 0            | 4         | 48472                   | 48472         | 48472  | 48472  | 48472     | 48472  |
|                       | SSWF (FUNCTIONAL)    | 1200                | 6059            | 1800      | 0            | 2         | 18177                   | 18177         | 18177  | 18177  | 18177     | 18177  |
|                       | PCS                  | 195                 | 1181            | 195       | 0            | 4         | 4724                    | 4724          | 4724   | 4724   | 4724      | 4724   |
|                       | PCS                  | 20                  | 121             | 160       | 0            | 10        | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | PCS                  | 70                  | 424             | 700       | 0            | 20        | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | PCS                  | 200                 | 1211            | 300       | 0            | 4         | 7266                    | 7266          | 7266   | 7266   | 7266      | 7266   |
|                       | PCS                  | 120                 | 727             | 180       | 0            | 10        | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | ARCS                 | 650                 | 3938            | 2600      | 0            | 5         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | CSW                  | 100                 | 605             | 800       | 600          | 10        | 0                       | 12100         | 0      | 0      | 0         | 0      |
|                       | SYSTEM TOTAL         |                     | 20325           | 9075      |              |           | 78639                   | 50739         | 180394 | 180394 | 180394    | 150133 |
| VEHICLE CONFIG. SYS.  |                      |                     |                 |           |              |           |                         |               |        |        |           |        |
|                       | EXT. TANK SEP. LCGIC | 30                  | 151             | 30        | 0            | 10        | 1510                    | 1510          | 1510   | 1510   | 1510      | 1510   |
|                       | LANDING GEAR         | 60                  | 363             | 60        | 0            | 20        | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | LOCKING              | 100                 | 605             | 125       | 0            | 10        | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | FOAG CMLE            | 18                  | 109             | 18        | 0            | 5         | 0                       | 0             | 0      | 0      | 0         | 0      |
|                       | SYSTEM TOTAL         |                     | 1228            | 233       |              |           | 1510                    | 1510          | 1510   | 1510   | 1510      | 1510   |

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|--------|--|----------|--|--|--|--|--|------------------|--|
| REV. A |  | 12/21/73 |  | BINGHAMTON, NEW YORK                               |  |  |  | REP. NO.         |  |

| SMS COMPUTER LOADING OF 12/13/73 AT 14:53:12 |  |           |  |                     |  |                 |  |                              |  | FIXED BASE STATION                            |  | PAGE 2         |  |        |  |        |  |        |  |
|--|--|-----------|--|---------------------|--|-----------------|--|------------------------------|--|---|--|----------------|--|--------|--|--------|--|--------|--|
| SYSTEM                                       |  | SUBSYSTEM |  | NUMBER OF EQUATIONS |  | NUM. OF INST.'S |  | DATA# PROG. BASE BUFFER RATE |  | ITER INSTRUCTIONS PER SECOND BY MISSION PHASE |  | ENTRY APP/LAND |  | FERRY  |  |        |  |        |  |
| COPM. / TRACKING                             |  | TACAN     |  | 200                 |  | 1211            |  | 10600                        |  | 10000   |  | 10             |  | 36330  |  | 36330  |  | 36330  |  |
| WATH SUBROUTINES                             |  | TRIG      |  |                     |  |                 |  |                              |  | 3870  |  |                |  | 3870   |  | 3870   |  | 3870   |  |
| ATRG   |  |           |  |                     |  |                 |  |                              |  | 3480  |  |                |  | 3480   |  | 3480   |  | 3480   |  |
| ILC/MSC                                      |  | 200       |  | 1211                |  | 400             |  | 0                            |  | 10  |  |                |  | 3027   |  | 3027   |  | 24220  |  |
| WATH SUBROUTINES                             |  | TRIG      |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 3870   |  |
| ATRG   |  |           |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 3480   |  |
| SOAT   |  |           |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 2520   |  |
| FRAP ALTIMETER                               |  | 120       |  | 727                 |  | 5240            |  | 5000                         |  | 10  |  | 1454           |  | 1454   |  | 1454   |  | 14540  |  |
| WATH SUBROUTINES                             |  | LEI(12)   |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 1000   |  |
| ATC TRANSDUCER                               |  | 10        |  | 60                  |  | 20              |  | 0                            |  | 1   |  |                |  | 0      |  | 0      |  | 1000   |  |
| S-PAN COUN.                                  |  | 125       |  | 631                 |  | 250             |  | 0                            |  | 2   |  | 2524           |  | 2524   |  | 2524   |  | 2524   |  |
| UKE COUN.                                    |  | 125       |  | 631                 |  | 250             |  | 0                            |  | 2   |  | 2524           |  | 2524   |  | 2524   |  | 2524   |  |
| TELEMETRY LOGIC                              |  | 240       |  | 969                 |  | 3980            |  | 3500                         |  | 2   |  | 3876           |  | 3876   |  | 3876   |  | 3876   |  |
| PCE IN                                       |  | 500       |  | 2019                |  | 500             |  | 0                            |  | 2   |  | 4038           |  | 4038   |  | 4038   |  | 4038   |  |
| PCE MT                                       |  | 600       |  | 2423                |  | 600             |  | 0                            |  | 10  |  | 24230          |  | 24230  |  | 24230  |  | 24230  |  |
| TV CONTROL LOGIC                             |  | 125       |  | 631                 |  | 125             |  | 0                            |  | 2   |  | 1262           |  | 1262   |  | 1262   |  | 1262   |  |
| REFERENCE CONTROL                            |  | 24        |  | 121                 |  | 48              |  | 0                            |  | 5   |  | 1210           |  | 1210   |  | 1210   |  | 1210   |  |
| WFE COUN.                                    |  | 125       |  | 757                 |  | 250             |  | 0                            |  | 2   |  | 3028           |  | 3028   |  | 3028   |  | 3028   |  |
| INTERCOM SWITCHING                           |  | 125       |  | 631                 |  | 250             |  | 0                            |  | 2   |  | 2524           |  | 2524   |  | 2524   |  | 2524   |  |
| ANTENNA PATTERNS                             |  | 125       |  | 631                 |  | 2125            |  | 2000                         |  | 2   |  | 1262           |  | 1262   |  | 1262   |  | 1262   |  |
| BINGHAM DATA LINK                            |  | 10        |  | 40                  |  | 10              |  | 0                            |  | 5   |  | 200            |  | 200    |  | 200    |  | 200    |  |
| SYSTEM TOTAL                                 |  |           |  | 12693               |  | 24648           |  |                              |  |   |  | 94839          |  | 94839  |  | 94839  |  | 110574 |  |
| CENTREL DISPLAY                              |  | 600       |  | 4241                |  | 2400            |  | 0                            |  | 2   |  | 33928          |  | 33928  |  | 33928  |  | 33928  |  |
| GUIP/NAV/COM/PTCL                            |  | 1070*     |  | 1070                |  | 160             |  | 0                            |  | 20  |  | 117700         |  | 117700 |  | 117700 |  | 117700 |  |
| TVU  |  | 285*      |  | 285                 |  | 42              |  | 0                            |  | 10  |  | 15675          |  | 15675  |  | 15675  |  | 15675  |  |
| TVU  |  | 183*      |  | 183                 |  | 27              |  | 0                            |  | 5   |  | 5032           |  | 5032   |  | 5032   |  | 5032   |  |
| TVU  |  | 705*      |  | 705                 |  | 105             |  | 0                            |  | 2   |  | 7755           |  | 7755   |  | 7755   |  | 7755   |  |
| STAR TRACKER                                 |  | 240       |  | 1454                |  | 1320            |  | 0                            |  | 20  |  | 15994          |  | 15994  |  | 15994  |  | 15994  |  |
| PERCEPTUS RADAR                              |  | 150       |  | 908                 |  | 450             |  | 0                            |  | 5   |  | 1362           |  | 1362   |  | 1362   |  | 1362   |  |
| ATQ DATA COMPUTER                            |  | 100       |  | 605                 |  | 350             |  | 0                            |  | 10  |  | 21175          |  | 21175  |  | 21175  |  | 21175  |  |
| RATE SENSORS                                 |  | 50        |  | 302                 |  | 225             |  | 0                            |  | 20  |  | 27180          |  | 27180  |  | 27180  |  | 27180  |  |
| P.W. ACCELEROMETERS                          |  | 40        |  | 242                 |  | 160             |  | 0                            |  | 20  |  | 19360          |  | 19360  |  | 19360  |  | 19360  |  |
| WPS TVC                                      |  | 375       |  | 2272                |  | 1687            |  | 0                            |  | 20  |  | 204480         |  | 204480 |  | 204480 |  | 204480 |  |
| CMS TVC                                      |  | 300       |  | 1817                |  | 150             |  | 0                            |  | 20  |  | 90850          |  | 90850  |  | 90850  |  | 90850  |  |
| SOV TVC                                      |  | 375       |  | 2272                |  | 1125            |  | 0                            |  | 20  |  | 136320         |  | 136320 |  | 136320 |  | 136320 |  |
| AEROSUPP. CONT.                              |  | 450       |  | 2726                |  | 1350            |  | 0                            |  | 20  |  | 163560         |  | 163560 |  | 163560 |  | 163560 |  |
| TARGET VEH. GUTC.                            |  | 40        |  | 242                 |  | 120             |  | 0                            |  | 10  |  | 7260           |  | 7260   |  | 7260   |  | 7260   |  |
| WATH SUBROUTINES                             |  | TRIG      |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 0      |  |
| ATRG   |  |           |  |                     |  |                 |  |                              |  | 0   |  |                |  | 0      |  | 0      |  | 0      |  |
| SYSTEM TOTAL                                 |  |           |  | 15083               |  | 7871            |  |                              |  |   |  | 746495         |  | 831743 |  | 554792 |  | 636849 |  |
|  |  |           |  |                     |  |                 |  |                              |  |   |  |                |  |        |  |        |  | 497901 |  |
|  |  |           |  |                     |  |                 |  |                              |  |   |  |                |  |        |  |        |  | 407051 |  |

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THE SINGER COMPANY  
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REV.A 12/21/73

BINGHAMTON, NEW YORK

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PAGE 4

CSC COMPUTER LOADING OF 12/13/73 AT 14:53.12 FIXED BASE STATION

| SYSTEM                  | SUBSYSTEM | NUMBER OF EQUATIONS | NUM. OF INST.'S | DATA BASE | PRG. BUFFER | ITER RATE | INSTRUCTIONS PER SECOND | PHASE ENTRY | APPL/LAND | FERRY |
|-------------------------|-----------|---------------------|-----------------|-----------|-------------|-----------|-------------------------|-------------|-----------|-------|
| OCCUPATIONS OF MOTION   |           |                     |                 |           |             |           |                         |             |           |       |
| SHUTTLE TRN. EOM HI     |           | 195                 | 1181            | 253       | 0           | 20        | 21258                   | 28344       | 24801     | 30706 |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 4000                    | 4000        | 4000      | 16534 |
| VECTER ROTATION         |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| MATRIX MULT             |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TRIG                    |           |                     |                 |           |             |           | 6020                    | 6020        | 6020      | 0     |
| ATRIG                   |           |                     |                 |           |             |           | 11600                   | 11600       | 11600     | 3480  |
| SORT                    |           |                     |                 |           |             |           | 6480                    | 6480        | 6480      | 1440  |
| SHUTTLE TRN. EOM LO     |           | 90                  | 545             | 450       | 0           | 0+        | 0                       | 340         | 0         | 0     |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| SORT                    |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| SHUTTLE POT. EOM        |           | 105                 | 636             | 420       | 0           | 20        | 50880                   | 50880       | 50880     | 50880 |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| SCRT                    |           |                     |                 |           |             |           | 720                     | 720         | 720       | 720   |
| TRIG                    |           |                     |                 |           |             |           | 2580                    | 2580        | 2580      | 2580  |
| ATRIG                   |           |                     |                 |           |             |           | 3480                    | 3480        | 3480      | 3480  |
| SHUTTLE ACT. BEARING    |           | 750                 | 4544            | 2250      | 0           | 20        | 0                       | 272640      | 0         | 0     |
| SHUTTLE POT. SLOSH      |           | 75                  | 454             | 1350      | 0           | 20        | 0                       | 163440      | 0         | 0     |
| SHUTTLE POT. ELASTIC    |           | 667                 | 4042            | 2001      | 0           | 20        | 0                       | 0           | 0         | 0     |
| SHUTTLE MASS PROP.      |           | 40                  | 242             | 480       | 0           | 10        | 29040                   | 29040       | 18150     | 20570 |
| SHUTTLE AERG            |           | 255                 | 1545            | 9153      | 9000        | 20        | 0                       | 13905       | 6180      | 18540 |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 7740        | 0         | 7740  |
| ATRIG                   |           |                     |                 |           |             |           | 0                       | 3480        | 3480      | 3480  |
| SORT                    |           |                     |                 |           |             |           | 0                       | 1440        | 1440      | 1440  |
| VECTER ROTATION         |           |                     |                 |           |             |           | 0                       | 1000        | 1000      | 1000  |
| RANDOM NO.              |           |                     |                 |           |             |           | 0                       | 6000        | 6000      | 6000  |
| LF(1)                   |           |                     |                 |           |             |           | 0                       | 12500       | 2500      | 6000  |
| LF(12)                  |           |                     |                 |           |             |           | 0                       | 5000        | 9000      | 37000 |
| LF(13)                  |           |                     |                 |           |             |           | 0                       | 0           | 0         | 22000 |
| TARGET VEN. TRN. EOM HI |           | 215                 | 1302            | 967       | 0           | 10        | 0                       | 19530       | 58590     | 0     |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 1000        | 3000      | 0     |
| VECTER ROTATION         |           |                     |                 |           |             |           | 0                       | 2580        | 7740      | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 4640        | 13920     | 0     |
| ATRIG                   |           |                     |                 |           |             |           | 0                       | 3600        | 10800     | 0     |
| SORT                    |           |                     |                 |           |             |           | 0                       | 355         | 1065      | 0     |
| TARGET VEN. TRN. EOM LO |           | 95                  | 575             | 1425      | 0           | 0+        | 0                       | 0           | 0         | 0     |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| SORT                    |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TARGET VEN. ROT. EOM    |           | 130                 | 787             | 780       | 0           | 10        | 0                       | 15740       | 47220     | 0     |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| SCRT                    |           |                     |                 |           |             |           | 0                       | 1680        | 1080      | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 360         | 3870      | 0     |
| MATRIX MULT             |           |                     |                 |           |             |           | 0                       | 1000        | 3000      | 0     |
| TARGET MASS PROP        |           | 15                  | 90              | 90        | 0           | 2         | 0                       | 360         | 1080      | 0     |
| TARGET VEN. AERG        |           | 35                  | 212             | 3087      | 3000        | 10        | 0                       | 1802        | 5300      | 0     |
| MATH SUBROUTINES        |           |                     |                 |           |             |           | 0                       | 0           | 0         | 0     |
| TRIG                    |           |                     |                 |           |             |           | 0                       | 860         | 2580      | 0     |
| ATRIG                   |           |                     |                 |           |             |           | 0                       | 1160        | 3480      | 0     |
| VECTER ROTATION         |           |                     |                 |           |             |           | 0                       | 500         | 1500      | 0     |
| SORT                    |           |                     |                 |           |             |           | 0                       | 360         | 1080      | 0     |
| LF(1)                   |           |                     |                 |           |             |           | 0                       | 500         | 1500      | 0     |
| LF(12)                  |           |                     |                 |           |             |           | 0                       | 4000        | 12000     | 0     |

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| SWS COMPUTER LOADING OF 12/13/73 AT 14.55.12 FIXED BASE STATION |           |                     |                 |            |              |           |                         |                  |         | PAGE 5   |         |
|---|-----------|---------------------|-----------------|------------|--------------|-----------|-------------------------|------------------|---------|----------|---------|
| SYSTEM  | SLPSYSTEM | NUMBER OF EQUATIONS | NUN. OF INST.'S | DATA3 BASE | PROG. BUFFER | ITER RATE | INSTRUCTIONS PER SECOND | BY MISSION PHASE | ENTRY   | APP/LAND | FERRY   |
| EPTWEPERS   |           | 40                  | 242             | 24         | 0            | 10        | 484                     | 1452             | 1452    | 1452     | 484     |
| DATA SUBROUTINES  |           |                     |                 |            |              |           |                         |                  |         |          |         |
| TRIG  |           |                     |                 |            |              |           | 860                     | 860              | 860     | 860      | 860     |
| VECTOR NORM   |           |                     |                 |            |              |           | 0                       | 1000             | 1000    | 1000     | 0       |
| SYSTEM TOTAL  |           |                     | 16397           | 22730      |              |           | 143402                  | 653238           | 338188  | 666453   | 204220  |
| THERMAL SYSTEMS   |           |                     |                 |            |              |           |                         |                  |         |          |         |
| COYGENICS   |           | 100                 | 706             | 200        | 0            | 2         | 2824                    | 2824             | 2824    | 2824     | 2824    |
| FCS LP  |           | 1346                | 9516            | 2422       | 0            | 1         | 17128                   | 17128            | 17128   | 17128    | 17128   |
| FCS MFO   |           | 1247                | 8816            | 1745       | 0            | 2         | 24684                   | 24684            | 24684   | 24684    | 24684   |
| FCS PI  |           | 670                 | 4736            | 670        | 0            | 5         | 23680                   | 23680            | 23680   | 23680    | 23680   |
| SYSTEM TOTAL  |           |                     | 23774           | 5037       |              |           | 68316                   | 68316            | 68316   | 68316    | 68316   |
| PAYLOAD ATTACHMENT  |           | 140                 | 848             | 700        | 0            | 10        | 0                       | 42400            | 0       | 0        | 0       |
| DATA SUBROUTINES  |           |                     |                 |            |              |           |                         |                  |         |          |         |
| VECTOR ROTATION   |           |                     |                 |            |              |           | 0                       | 0                | 4000    | 0        | 0       |
| SORT  |           |                     |                 |            |              |           | 0                       | 0                | 360     | 0        | 0       |
| SYSTEM TOTAL  |           |                     | 2300            | 13937      | 23000        | 0         | 10                      | 2787             | 1393700 | 2787     | 2787    |
| MATH SUBROUTINES  |           |                     |                 |            |              |           |                         |                  |         |          |         |
| TRIG  |           |                     |                 |            |              |           | 860                     | 860              | 860     | 860      | 0       |
| VECTOR POTATION   |           |                     |                 |            |              |           | 0                       | 0                | 16000   | 0        | 0       |
| MATRIX MULT   |           |                     |                 |            |              |           | 0                       | 0                | 1000    | 0        | 0       |
| SYSTEM TOTAL  |           |                     | 130             | 787        | 1040         | 0         | 10                      | 0                | 62960   | 0        | 0       |
| MATH SUBROUTINES  |           |                     |                 |            |              |           |                         |                  |         |          |         |
| TRIG  |           |                     |                 |            |              |           | 0                       | 0                | 860     | 0        | 0       |
| VECTOR POTATION   |           |                     |                 |            |              |           | 0                       | 0                | 16000   | 0        | 0       |
| MATRIX MULT   |           |                     |                 |            |              |           | 0                       | 0                | 1000    | 0        | 0       |
| SYSTEM TOTAL  |           |                     | 25              | 151        | 25           | 0         | 5                       | 755              | 755     | 755      | 755     |
| PAYLOAD ILLUMINATION  |           | 70                  | 424             | 70         | 0            | 5         | 2120                    | 2120             | 2120    | 2120     | 2120    |
| SYSTEM TOTAL  |           |                     | 16147           | 24835      |              |           | 6522                    | 1526755          | 6522    | 6522     | 2375    |
| SIMULATOR CONTROL   |           |                     |                 |            |              |           |                         |                  |         |          |         |
| DATA RECORDING  |           | 750*                | 750             | 1712       | 1600         | 20        | 18000                   | 18000            | 18000   | 18000    | 18000   |
| REALTIME I/O  |           | 2200*               | 2200            | 1029       | 700          | 25        | 55000                   | 55000            | 55000   | 55000    | 55000   |
| EFFECTIVE   |           | 400*                | 400             | 1059       | 1000         | 20        | 6400                    | 6400             | 6400    | 6400     | 6400    |
| MASTER TIMING   |           | 1000*               | 1000            | 149        | 0            | 20        | 20000                   | 20000            | 20000   | 20000    | 20000   |
| MASTER CONTROL  |           | 4500*               | 4500            | 674        | 0            | 20        | 13500                   | 13500            | 13500   | 13500    | 13500   |
| ORIGON PLAYBACK   |           | 4500*               | 4500            | 1674       | 1000         | 5         | 67500                   | 67500            | 67500   | 67500    | 67500   |
| POT   |           | 5000*               | 5000            | 41749      | 41000        | 2         | 57000                   | 57000            | 57000   | 57000    | 57000   |
| SYSTEM TOTAL  |           |                     | 18350           | 48046      |              |           | 237400                  | 237400           | 237400  | 237400   | 237400  |
| TOTALS  |           |                     | 153598          | 154393     |              |           | 1633833                 | 2324921          | 3273496 | 2125893  | 1615656 |

\* REPRESENTS AN INPUT NUMBER OF INSTRUCTIONS WHERE THE NUMBER OF EQUATIONS WAS UNAVAILABLE  
\* ACS-STANDARD RATE (1 PER 8 SECONDS)  
\* DATA PAGE TOTAL INCLUDES PROGRAM BUFFER

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MISSION PHASES

The Mission Phases as discussed in the computer loadings are defined as follows:

PRELAUNCH: The Mission Phase covering all time up to first motion.

BOOST: All time from first motion until SSME shutdown.

ORBIT: All time from SSME shutdown until significant aerodynamic acceleration.

ENTRY: All time from detection of significant aerodynamic acceleration after SSME shutdown until a (TBD) altitude is reached.

APPROACH/LANDING: All time from a (TBD) altitude is reached after SSME shutdown until end of the rollout and taxi.

FERRY: All time during which the ABPS is installed.

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COMPUTER LOADING SUMMARYWORST CASE:

|                                   |                  |        |
|-----------------------------------|------------------|--------|
| MBCS (LAUNCH BOOST)               | 2,316,884        |        |
| FBGS (ORBIT/PAYLOAD MANIPULATION) | <u>3,273,496</u> |        |
| SUBTOTAL                          | 5,590,380        | I.P.S. |
| SPARE (25% of SUBTOTAL)           | <u>1,397,595</u> |        |
| SUBTOTAL                          | 6,987,975        | I.P.S. |
| OPERATING SYSTEM                  | <u>500,000</u>   |        |
| SUBTOTAL                          | 7,487,975        | I.P.S. |
| TIME SHARING                      | <u>700,000</u>   |        |
| TOTAL                             | <u>8,187,975</u> | I.P.S. |

INCLUDED IN ABOVE, BUT REQUIREMENTS FOR TRAINING NOT PROVEN BY THE STUDY:

| <u>OPTION</u>      | <u>MISSION PHASE</u> | <u>IPS</u> |
|--------------------|----------------------|------------|
| STRUCTURAL BENDING | BOOST                | 272,640    |
| LIQUIDS SLOSH      | BOOST                | 163,440    |
| AEROELASTICITY     | ENTRY                | 242,520    |

NOT INCLUDED IN ABOVE AND REQUIREMENTS FOR TRAINING NOT PROVEN BY THE STUDY:

| <u>OPTION</u>       | <u>MISSION PHASE</u> | <u>IPS</u> |
|---------------------|----------------------|------------|
| MANIPULATOR BENDING | ORBIT                | 300,000    |
| AEROSURFACE FLUTTER | ENTRY AND/OR BOOST   | 48,000     |

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3.0 Hardware Baseline Definition

3.1 Government Furnished Property (GFP)

The following Government Furnished Property (GFP) will be provided to the SMS Contractor and incorporated into the SMS MBCS and FBCS Simulator.

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3.1.1 MECS Government Furnished Property

- a. Simulation Computer Complex
  - 1. Computer and Peripheral Hardware
  - 2. Software
- b. Shuttle Data Package
- c. Flight Software Data Plan
- d. Flight Software Programs
- e. Crew Station Seats 4
- f. Data Processing and Software Subsystem Equipment
  - 1. Computers 4
  - 2. Mass Memory Units 2
  - 3. CRT Displays 4
  - 4. Display Electronics Units 4
  - 5. Keyboards 3
- g. Recorders 2
- h. Hand Controller, Rotational 2
- i. Hand Controller, Translational 2

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3.1.2 FBCS Government Furnished Property

- a. Simulation Computer Complex
  - 1. Computer and Peripheral Hardware
  - 2. Software
- b. Shuttle Data Package
- c. Flight Software Data Plan
- d. Flight Software Programs
- e. Crew Station Seats 4
- f. Data Processing and Software Subsystem Equipment
  - 1. Computers 5
  - 2. Mass Memory Units 2
  - 3. CRT Displays 5
  - 4. Display Electronics Units 5
  - 5. Keyboards 4
- g. Recorders 2
- h. Hand Controller, Rotational 3
- i. Hand Controller, Translational 3
- j. Manipulator Arm Controls, Set 1

The Simulation Computer Complex will be shared by the MBCS, the FBCS, and additional NASA Data Management and Program Processing activities.

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### 3.2 Motion Based Crew Station Equipment

The equipment requirements of the MBCS are defined in Figure 3.2-1. The requirements of each major area are as follows:

a) Crew Station - The crew station will be compatible with the motion system and forward visual system and provide the following features:

(i) An active hi-fidelity replica of the Commander and Pilot work stations.

(ii) Aft structure and interior adequate to incorporate the seats for the Mission Specialist and the Payload Specialist.

(iii) Mock-up Aft Work stations to the extent necessary to provide Crew Station realism forward of the Payload/Mission Specialist seat positions. Only those controls and displays which are required for flight control will be active at the aft work stations.

(iv) A removable jump seat IOS.

b) Motion System - The MBCS motion system major requirements are:

(i) Six Degrees of Freedom

(ii) State-of-the-art Synergistic Floor Mounted System

(iii) Redundant Legs

(iv) Cascaded Tilt Axis enabling the Crew Station X-body axis to pitch up beyond  $90^{\circ}$ .

c) Forward Visual System

(i) Full Field of View Display System

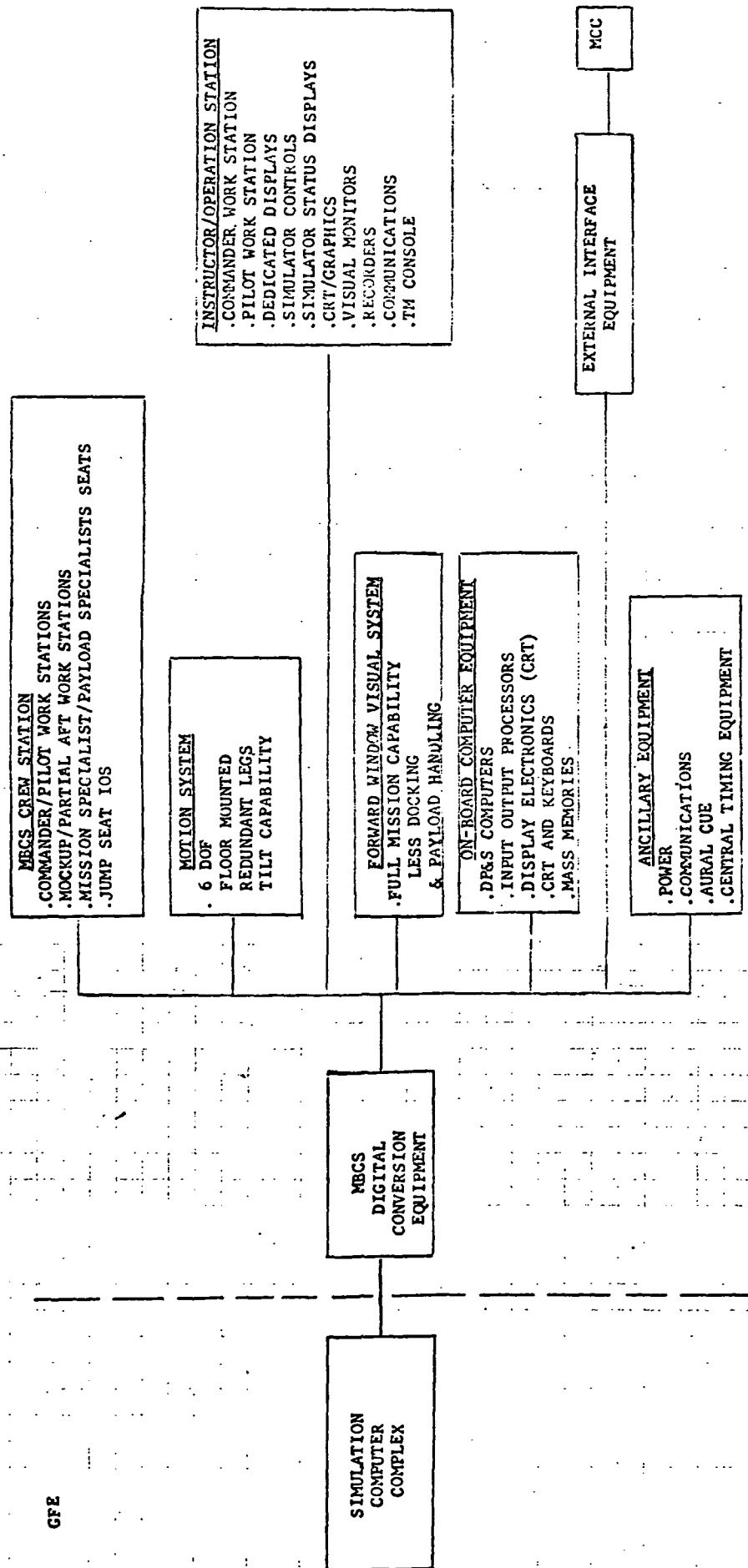


FIGURE 3-2-1 MOTION BASED CREW STATION EQUIPMENT REQUIREMENTS

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(ii) Capable of all scene requirements except  
Docking and Payload Operations.

d) On-Board Computer Equipment - This equipment will provide the  
capability of simulating the vehicle's on-board computers to include:

- (i) Data Processing and Software Subsystems
  - a) DP&S Computers
  - b) Input Output Processors
  - c) Display Electronics Units
  - d) Keyboard & Display Equipment
  - e) Mass Memories

The simulation of the on-board computer equipment will be  
capable of handling the redundancy of computers and the resulting switch-  
overs for malfunction situation, and for the utilization of flight  
software.

e) Instructor Operator Station - The Instructor Operator Station  
for the MECS will be capable of providing the following capabilities:

- (i) Commander Work Station
- (ii) Pilot Work Station
- (iii) Dedicated Monitoring Displays
- (iv) Simulator Status Displays
- (v) Simulator Controls
- (vi) CRT/Graphic System
- (vii) Visual Monitors
- (viii) Data Recording Equipment
- (ix) Communications Equipment
- (x) Telemetry Console

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The design will be such as to enable two instructors to accomplish training in the non-integrated mode.

f) External Interface Equipment - Equipment which will enable the MBCS to operate in a closed loop mode with MCC will be provided.

g) Ancillary Equipment - Ancillary equipment requirements fall into a variety of areas namely:

(i) Aural Cue - Equipment will be provided to duplicate the sound heard within the orbiter vehicle during its missions.

(ii) Power - Equipment will be provided to enable building power to be converted to the power types and levels required to operate the MBCS equipment.

(iii) Communications - Equipment will be provided to enable communications between the simulated crew station, IOS, Maintenance areas and MCC.

(iv) Central Timing Equipment - Timing signals will be provided to enable the MBCS, SCC and MCC to operate in a synchronized manner.

(v) Interface Equipment

h) MBCS Digital Conversion Equipment - Data Conversion Equipment will be provided including a minicomputer interface, Analog Input, Analog Output, Discrete Input, Discrete Output, Electronic Synchro/Resolver Drivers, and associated closed loop DCE test equipment.

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### 3.2.1 MPCS Crew Station

The crew station for the motion based simulator will contain all of the controls, displays, linings, seats and other equipment, in the precise location of that in the actual vehicle, which are visible to the Commander and Pilot in the performance of their duties. Aft of this flight compartment the fidelity will be compromised to include the authentic seating provisions for the Mission and Payload Specialists but will include only those displays or controls at these stations which are associated with flight control.

In addition, a removable jump seat will be provided for an observer to be located aft of the center pedestal and approximately six inches above the flight crew. This jump seat can be readily removed and contains seat belts to restrain the observer. It will be braced structurally to accommodate the observer in a full tilt attitude under the maximum dynamic loads.

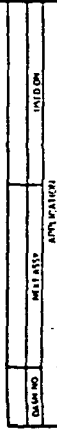
Normal ingress/egress for the crew members will be through a conventional hinged door, approximately 28" W. x 72" H., at the rear of the crew station, while the crew station is in a level position. An emergency hatch will be provided above the Payload Handling Station, as in the Orbiter, to permit egress when the crew station is in a tilt position and the aft door is blocked by the platform.

The crew station is approximately 123" long x 148" wide and 85-1/8" high and, complete with 4 crew members, weighs an estimated 6,000 lbs.

(Reference Figure 3.2.1-1).

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With reference to a crew eye position at Sta. 498 and W.L. 469 it extends longitudinally from approximately Sta. 450 aft to Sta. 573 (all B.L., W.L. and Station references refer to NR Drawing VL70-003268. Vertically it extends from W.L. 411, approximately 8" beneath the crew station floor, to approximately W.L. 496 to permit installation of the lining around the overhead panels. Laterally, it extends to B.L. 74 to include the panels beneath the Mission Specialist's and Payload Specialist's stations on each side and to provide space for cabling and interfaces in this area.

It will be made in two discrete sections, a forward and aft section split at approximately Sta. 516, to accommodate shipping and to permit using identical forward sections for the motion based and fixed base simulators. Thus, the assembled forward section will be approximately 148" long x 66" wide x 85" high, and the aft section 148" long x 59" wide x 85" high.

The forward section will be tapered to nest within the forward visual system. The interior will be a high fidelity replica of the actual vehicle.

The aft section will be a less authentic replica of its vehicle counterpart except in the areas associated with flight control.

It will be authentic in interior size and will extend to the aft bulkhead of the orbiter. The entrance hatch in the floor will be dummied since ingress is not possible thru the floor when the crew

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station is mounted on the motion platform/tilt frame. Laterally the width from the floor level to the shelf level will be compromised by creating a vertical plane at B.L. 74 to accommodate a bearing surface to transfer side loading to the tilt frame and to minimize the width of the tilt frame structure. The aft bulkhead detail also will be compromised to incorporate the main entrance door.

#### 3.2.1.1 Crew Station Structure

The crew station for the MECS will be made in two sections. Each section will be designed to be as light as practical consistent with cost and rigidity requirements. Further, access and maintainability are prime considerations. It will be possible to remove the entire cockpit from the tilt frame without disturbing the visual alignment.

To accomplish these objectives, each section will be complete with its floor frame, shell, seat linings, panels and cabling, requiring only structural and electrical connections to form the complete unit. The assembled crew station will be sufficiently reinforced to permit removal from the tilt frame without major disassembly.

The floor frames will be welded aluminum frames simulating the floor frames of the vehicle and extending upward to support the majority of the weight of the consoles, panels and seats and to transfer these loads to the tilt frame structure. The floor frame at the rear will be compromised with a fixed frame replacing the operable floor hatch.

|                 |  |                  |
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A molded fiberglass shell will form the outer structure above the floor levels. The forward shell will contain the structural sills, inner window framing, and additional flanges to support overhead panels, lining, outer console attachments and upper attachments to the tilt frame structure. The aft shell will be reinforced to contain the entrance door, emergency escape hatch, and overhead attachment to the tilt structure, and also to provide a bearing surface to transfer side loading to the tilt pivot structure close to the motion platform. The interior of the aft section will match the interior of the orbiter such that actual spacecraft equipment can be installed, except that it will terminate at B.L. 72 to reduce the width of the tilt structure.

The six forward windows will be sub-assemblies protruding outward from the inner window framing and simulating the field of view as restricted by the multi-paned vehicle windows.

To the greatest extent possible all panels will contain provisions for removal for maintenance from within the cockpit, since external access is obstructed by the visual system.

### 3.2.1.2 Control Loading

The control loading for the MBCS will be defined by the characteristics of the individual vehicle control forces, travels, and automatic drives. Some controls are purely electrically activated and require only the vehicle switch. Others require manual operation where control output is proportional to control handle position. Among the controls requiring loading mechanisms are the rudder, toe brakes, throttles, speed brakes, and vehicle attitude and translation controls. Simulation of each of these devices will be a function of their specific characteristics in the vehicle. Loading mechanisms include devices such as mechanical bungees, hydraulic actuators, pneumatic actuators, and combinations thereof depending on the vehicle operation and failures to be considered.

#### 3.2.1.2.1 Rudder Controls

The rudder controls are presently conceived to be conventional floor mounted dual controls typical of those on all large aircraft.

Typically, the rudder controls require high forces, hence an electrohydraulic control loading servo will be employed to simulate the characteristics of the rudder system. Hydraulic power for this loading unit is supplied with the standard motion system equipment which has a separate 10 HP pump and a distribution manifold which permits pressure regulation to that required for the loading units. The pump has sufficient capacity to accommodate the hydraulic requirements

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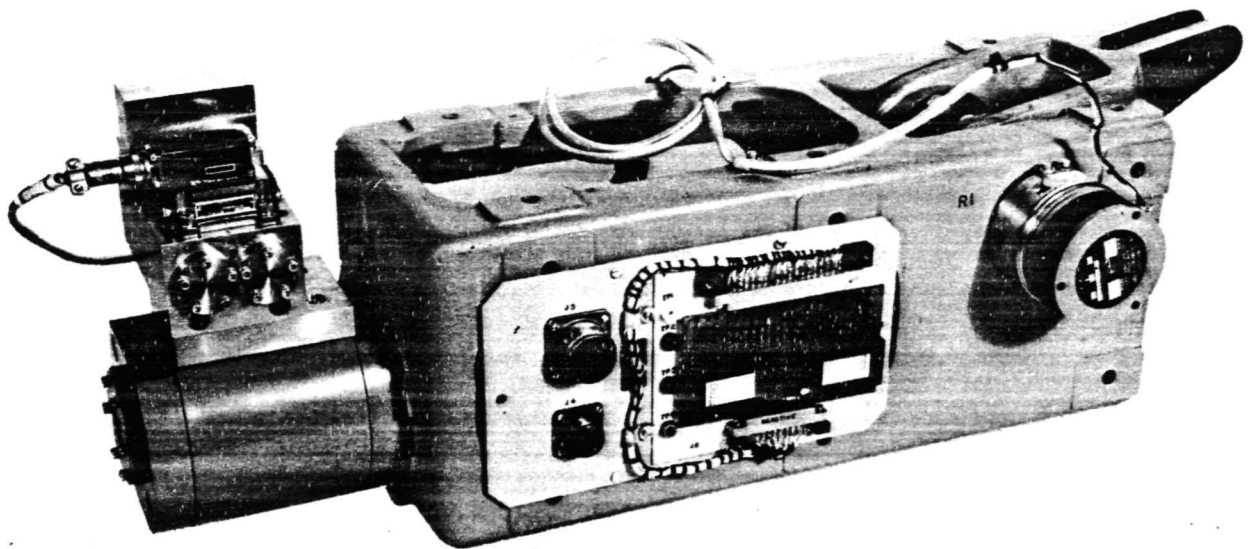


Figure 3.2.1-2 CONTROL LOADING SERVO

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of both the motion based and fixed base cockpits.

A typical control loading servo device, shown on Figure 3.2.1-2, is a closed loop servo system made up of the following major elements:

1) A semiconductor strain gauge load cell used as a force transducer. The load cell consists of four strain gauges arranged in a Wheatstone bridge. This bridge is balanced when the system is unloaded. The application of force or load causes two of the strain gauges to increase in resistance and two to decrease in resistance. The load cell uses the piezo-resistance characteristics of semiconductors to generate this effect. A DC output voltage is obtained (with polarity dependent upon tension or compression of the cell) by exciting the strain gauge with a DC voltage. The load cell has a nonlinearity less than  $\pm 0.003$  inches at full scale.

2) A film potentiometer used for sensing control position. The potentiometer has a  $\pm 0.25\%$  linearity and virtually infinite resolution.

3) Amplifiers and power supplies of solid state construction. To minimize pickup in the leads, critical amplifiers are located at the control loading servo.

4) A hydraulic/mechanical safety device which senses the rate of change of pressure as a function of flow. In the event that the triggering level of the device is exceeded, it automatically locks the control loading units, preventing further motion from taking place.

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By this action the pilot is protected from a sudden hardover servo failure that could produce a violent pedal motion.

The control loading system is a rigid servo loop which cannot be moved without an electrical input.

The output shaft of each servo is connected to the crew pedal arm through a force transducer. The force transducer produces an electrical signal (analogous to pilot force) that drives the servo in the direction of the force. The required force is computed and fed back to the pilot through the control. The force gradient is zero when the force transducer is the only input to the system.

This control loading device will be mounted in a location that will permit access for adjustment and maintenance.

#### 3.2.1.2.2 Throttles and Speed Brakes

Simulation for the throttle and speed brake controls will be a function of the specific characteristics of these controls in the vehicle. In the Shuttle vehicle, the throttle and speed brake controls incorporate a position sensing unit and slip clutch with electric-motor driven servoes employed for auto-throttle, or playback. The orbiter has dual controls for both throttles and speed-brake with one quadrant on the left console and the other quadrant on the center pedestal. These controls will be linked to common jackshafts located in the forward floor frame to facilitate interconnection. There are four throttle levers on the center pedestal and one on the left console.



Hence linkage may be quite intricate, depending upon actual vehicle interconnection and what failures are to be simulated.

### 3.2.1.2.3 Vehicle Attitude and Translation Controls

In addition to the rudder pedal sets the GN&C subsystem employs three rotation hand controllers and three translation hand controllers to accomplish manual attitude and translation control.

#### 3.2.1.2.3.1 Rotation Hand Controllers

The rotation hand controllers are located at the Command station, the pilots station and the payload handling station. However, only the commanders and pilots station controllers will be incorporated in the MBCS.

Each controller provides three (triple redundant) output signals proportional to rotations about each of three axis - roll, pitch and yaw.

#### 3.2.1.2.3.2 Translation Hand Controllers

Three translation controllers are also provided, located with the rotational controllers. Each controller provides a discrete DC signal for each degree of freedom of the controller ( $\pm X$ ,  $\pm Y$ ,  $\pm Z$ ). Each discrete is triple redundant. Only the two forward crew station translation controllers will be incorporated in the MBCS.

### 3.2.1.3 Crew Station Air Conditioning

Site supplied conditioned air will be used to ventilate the crew stations of the flight simulator. Air will be drawn from beneath the computer flooring of the IOS area into a filtered plenum by a

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booster blower which will augment the supply pressure to overcome the losses in the filter, flexible ducts to the crew station and visual system and outlet grilles. Refer to Figure 3.2.1-3.

The blower will run continuously to supply cooled air to instruments and to the visual system components. The air flow to the crew station will be ducted to a distribution plenum equipped with dampers and heaters which will respond to the flow/temperature settings of the spacecraft controls. The majority of the heat generated in the visual display will be removed by means of liquid cooling.

#### 3.2.1.4 Crew Station Suit System

The requirement for a pressure suit system in the Orbiter vehicle has not been established at this time. Therefore suit provisions have been excluded from this baseline design.

#### 3.2.1.5 Crew Station Control and Display

In the MBCS, each Crew Station control and display associated with the Shuttle Vehicle Commanders and Pilots Stations will be duplicated in appearance, location, color, action and reaction to the high degree required for crew training.

Additional MBCS crew station controls and displays associated with the Mission Specialist and Payload Handling will be simulated by mockup but will not be functional. Refer to Addendum A for panel outline drawings and crew station locations.

All cockpit lighting controls on simulated panels will be operative. Lighting will be variable where required and will be duplicated in visual light intensity to that of the space vehicle.

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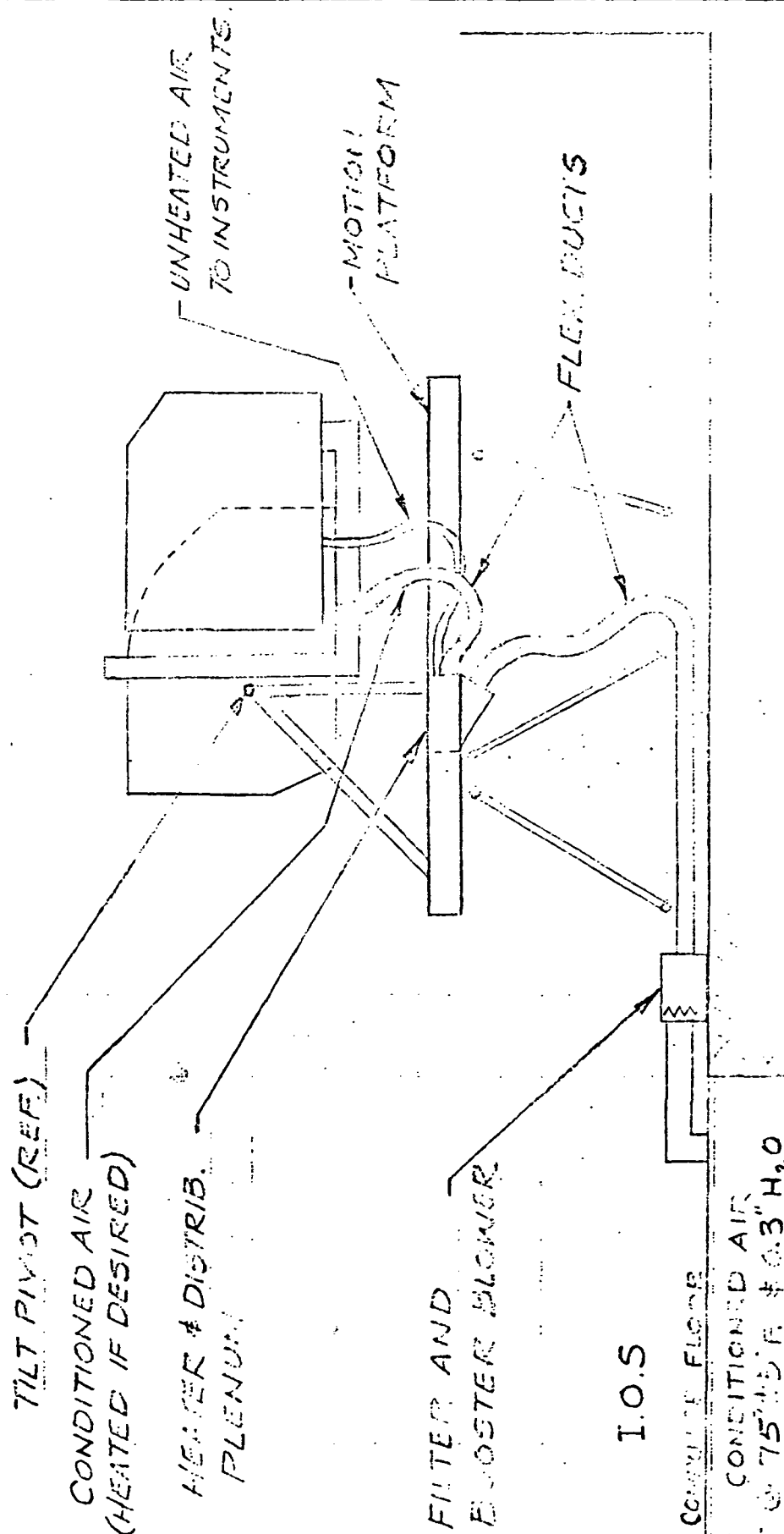
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NOTE: AIR FLOW IS 1000 CFM  
PER DUCT TO INSTRUMENTS

FIG. 3.2.1-3

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Electroluminescent lighting will be used where applicable and operate as in the spacecraft. Step-up transformers will be located near their loads to minimize pickup.

Power logic will be incorporated in all circuits and overload protection will be supplied.

The Data Processing and Software Subsystem CRT's and associated keyboards will be supplied GFP. This equipment is located on panel numbers 27, 29 and 8 on the MBCS and FBCS. Information will be transmitted to those devices through special data channels and will interface with the DP&S Subsystem computers without the need for DCE. The method for implementing these devices is discussed more fully in Section 3.2.4.

The audio communications system for the MBCS will include controls for simulated transmission and reception of S-Band, VHF-1, VHF-2, and the Intercom. The controls for external communication will not be simulated. The details for implementing this system are more completely described in Section 3.2.3.5.

The majority of crew station controls and displays will interface with the simulation computer complex through analog and digital Data Conversion Equipment (DCE) as described in Section 3.2.6.

Electrical system schematic diagrams for these typical SMS control and display functions are shown in Addendum B.

### 3.2.1.5.1 Analog Functions

Analog functions include potentiometers and other transducers for control or measurement, and D'Arsonval meter movement, and DC and AC servomechanisms for display and positioning.

For simulation purposes, these functions have been divided and categorized according to whether they require Analog Input devices, analog output devices, or combinations of the above.

Control knobs (potentiometers) and other continuously variable functions such as strain gauges will input their position to the computer via an analog-to-digital (A/D) device, located in the DCE. Included in this group are the Rotational Hand Controllers, position feedback from speed brakes, and throttles, and the control loading and motion system position sensing devices.

Meter Movement Instruments will be driven directly from a Digital to Analog Converter (D/A) through series, scaling resistors. Where possible these resistors will be mounted on the rear of the instrument thereby allowing setup by a single technician and eliminating the need for a circuit card in the peripheral cabinet.

AC Synchro Instruments, such as the Course Indicator (BDHI) and the FDAI (multiple synchros) will be driven by an Electronic Synchro Resolver Driver (ESRD) which, in turn, is driven from the DCE by a pair of Digital-to-Analog (D/A) Channels.

### 3.2.1.5.2 Discrete Functions

Discrete Digital Functions include such devices as switches,

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flag and lamp type indicators, decimal readouts, circuit breakers, shaft position encoders and other special devices.

For simulation purposes these functions are divided and categorized primarily on the basis of requiring Digital Input (DI), Digital Output (DO) or combinations of the above.

Digital Input Functions, such as toggle switches, momentary switches, and multiple position rotary switches, will interface with the computer through Digital Input devices (DI).

Multiple position switches will require (n) DI's, where n = the number of switch positions.

Illuminated switches also normally require one or more Digital Outputs (DO) to control the lights, and Digital Inputs for the switch functions.

Press-to-Test Indicators which require additional power logic for test will require two digital output (DO) control channels. Where the test position only requires a ground to test, the DO at the test position will be replaced with a ground point.

Flag and Lamp Indicators are controlled by digital outputs. Where one color is required, all bulbs will be wired together and only one DO will be used.

Decimal digital readouts have a built-in BCD decoder which accepts an 8, 4, 2, 1 code to display a 0 through 9 decimal readout. Each readout will be driven by discrete DO's or, by a digital-word-output (DWO).

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All crew station circuit breakers will be remotely poppable through the computer. Special, low-current circuit breakers will be used instead of spacecraft equipment for the SMS.

The breakers can be made to be "resettable" or "non-resettable" by means of programming. A "resettable" breaker can be reset by the student after it is remotely tripped; whereas a "non-resettable" breaker will trip or "pop" as soon as resetting is attempted.

Double-pole, double-throw contacts will enable the circuit breaker to feedback to the computer that it is tripped or pulled as well as having the capability of being hardwired in the simulated circuit.

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### 3.2.2 MBCS Instructor-Operator Station Complex

Several configurations of the Instructor-Operator Station (IOS) were considered for the SMS. The configurations were limited to a conventional-type IOS since the availability of space in the crew cabin precluded the consideration of extensive in-cabin instructor stations.

The configuration of the conventional IOS narrowed down to an IOS for the motion-base crew station and one for the fixed-base crew station. The IOS for the motion-base crew station will permit monitoring of training exercises for all phases of flight except docking and payload handling. The fixed-base IOS will accommodate instruction for all phases of flight associated with both space and aerodynamic operation. A separate IOS for each crew station provides the flexibility of instructing on both crew stations at the same time. A single IOS for both devices would not provide this feature, and would result in inefficient utilization of training time.

The motion-base crew station will be used primarily to train the Commander and Pilot. It will also be used to train the Mission Specialist and Payload Specialist in those duties required to assist the Commander and Pilot. Panels dedicated to Mission and Payload Specialist functions will not be functional in the motion-base crew station. As a result, the IOS associated with this crew station will be concerned with training relative to the forward cabin.

In addition to the Commander Pilot IOS, the MBCS IOS will



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include a Telemetry Operator Station and the following recording devices:

- a. One X-Y recorder
- b. Three eight-channel time history X-T recorders
- c. One hard-copy print-out device

Fully adjustable, castered, swivel arm chairs will also be provided for the use of the instructors and Telemetry Operator.

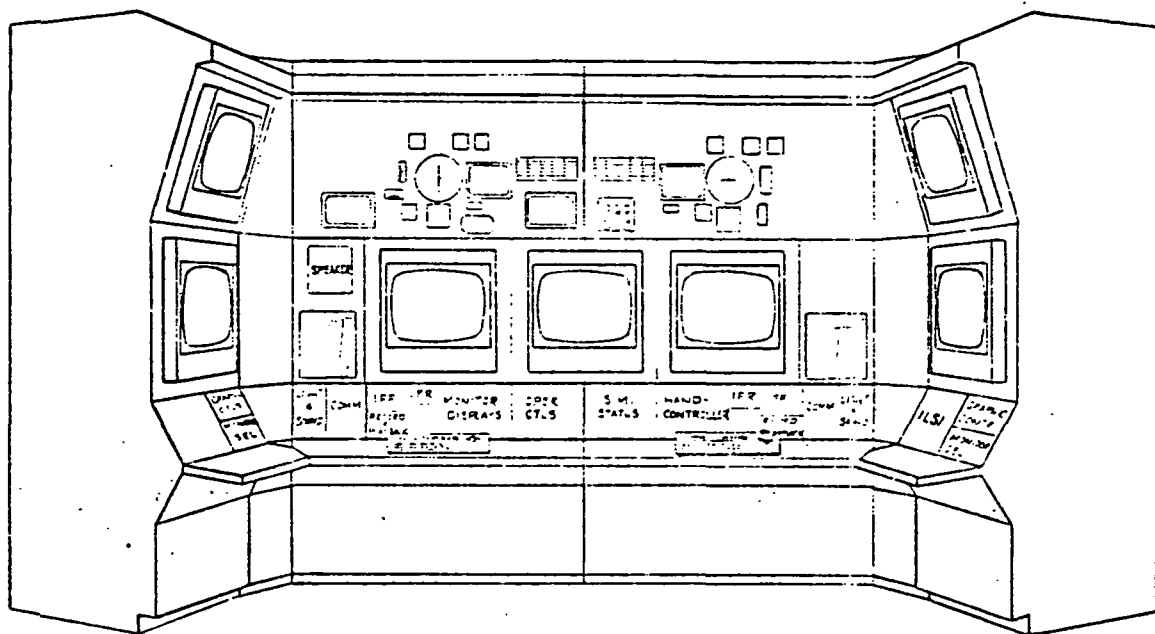
The capability also exists for an instructor to observe trainee performance in the motion-based simulator during those periods when the Mission Specialist or Payload Specialists' seats are not occupied.

A removable jump seat will also be provided for the use of an instructor or observer. On those occasions, limited control of the training exercise will be provided through a portable control box. On most occasions, instruction will be conducted from the conventional IOS.

#### 3.2.2.1 Commander/Pilot Instructor-Operator Station

The simulator complex will consist of two Commander/Pilot IOS's; one for the motion-based simulator, and one for the fixed-base simulator. Design of these IOS's will be identical except for those special controls required to perform training device peculiar functions. As an example, only the motion-based simulator will contain those controls required for the operation of the motion system.

The Commander/Pilot IOS is designed to be operated on most training exercises by two instructors; one for the Commander, and one



PILOT & COMM. CONSOLES  
 I/O STATION-  
 MBCS & FBCS SIM.

FIGURE 3.2.2-1

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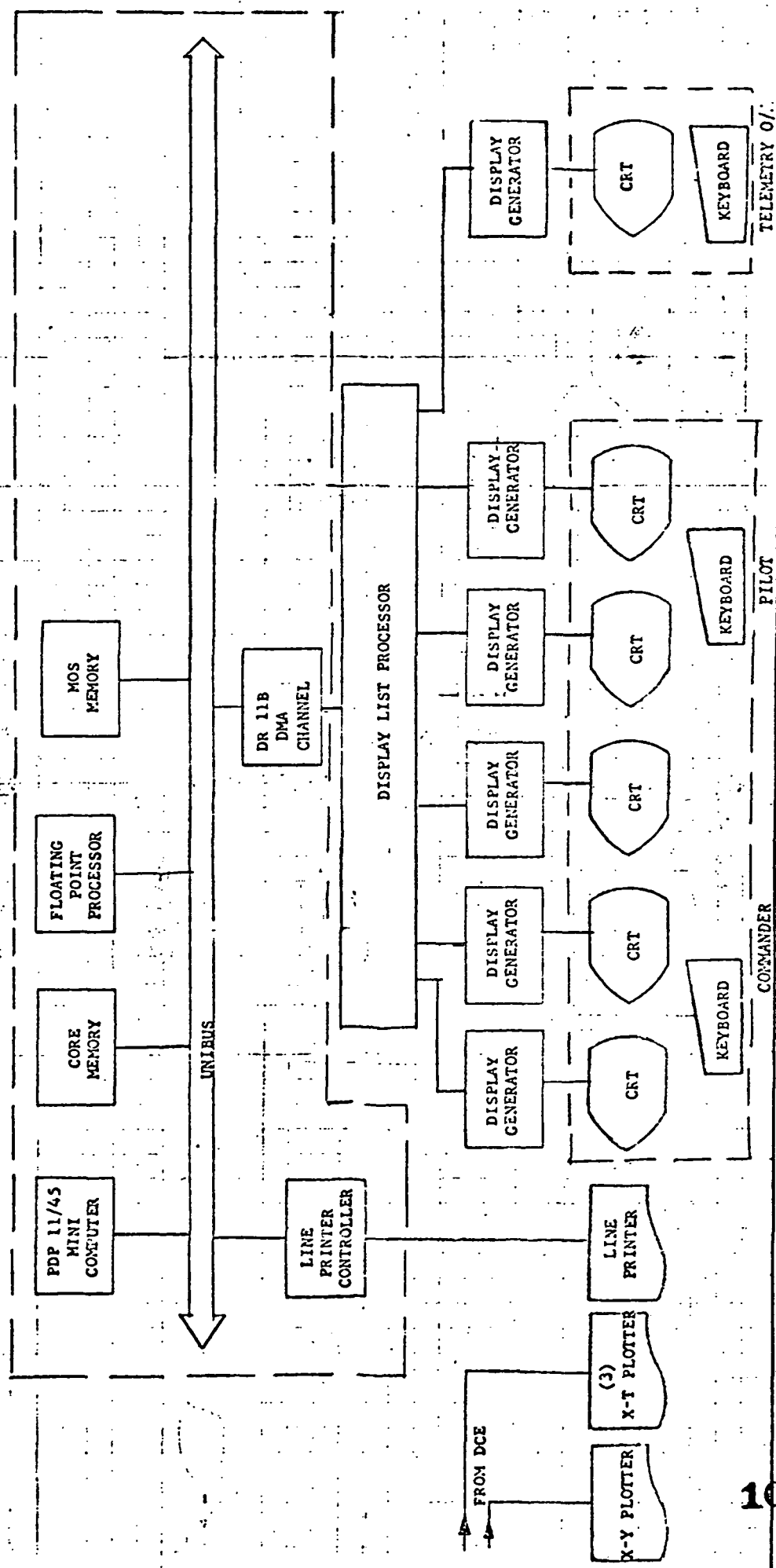
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for the Pilot. When training is to be conducted for just one crew member, only one instructor will be required to man the console.

The Commander/Pilot IOS console integrates five CRT display/keyboard units, two visual system monitors, dedicated displays, a control panel used for functions not accomplished with the keyboard units, and an audio panel to provide the necessary communications functions. (Reference Figure 3.2.2-1). The console utilizes horizontal wraparound to provide for ease of viewing the CRT's and monitors, and to facilitate interaction between the two instructors. The console is also vertically stacked. The upper segment is canted downward 30 degrees from the vertical, the middle segment is vertical, and the lower segment is included 45 degrees from the horizontal, and joins the horizontal writing surface. The writing surface is 16 inches deep to provide adequate space for reference materials (manuals, mission plans, etc.) and for writing. The height of the writing shelf above the floor (25½ inches, in conformity with MIL-STD-1472) allows the keyboard units to be at a comfortable level and yet provides ample knee room for the instructor.

The center portion of the instructor console contains the dedicated instruments on the upper segment. The vertical segment contains two alphanumeric CRT's and a CRT dedicated to Event Time Monitoring functions. The lower inclined segments contains operating controls. The left portion of the console is wrapped-around 45 degrees

FIGURE 3.2.2-2  
MCS IOS CRT DISPLAY SYSTEM BLOCK DIAGRAM



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and contains a visual system monitor on the upper segment, a graphic CRT on the vertical segment, and operating controls on the lower inclined segment. The right portion of the console, also wrapped-around 45 degrees, is a mirror image of the left portion of the console and also contains a visual motion monitor, a graphic CRT and operating controls.

#### 3.2.2.1.1 CRT Display/Keyboard Units

The IOS for the motion base crew station will contain provisions for two instructors; one for the Commander, and one for the Pilot. Each position of this station will be equipped with a sufficient number of CRT's for each instructor to completely monitor the performance of the crew members. To accomplish this objective, each instructor will be provided with two CRT's. The functions of the CRT's are to provide: (1) an alphanumeric display, (2) a graphic display, and (3) a monitor of the visual system. In addition, a fifth CRT, centrally located between the two instructors, will be provided to observe Event Time Monitoring functions (Refer to Figure 3.2.2-2). Additional monitors which duplicate the in-cabin CRT's will also be provided and located in the cluster of dedicated instruments centrally located between the two instructors.

#### 3.2.2.1.1.1 CRT Display System Requirements Analysis

The primary usage of the CRT Display system will be for display of alphanumeric data.

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Graphic displays will include bar-type meters and a few circular meters in the Panel Display page group and the Energy Management Predictor, Enroute and Approach, ILS/GCA and In-Flight Refueling.

Since there are no definite requirements for a color system, a monochromatic system is considered to be satisfactory for the baseline definition.

Requirements for three dimensional pictorial views, such as for an in-flight refueling display or rendezvous display can be eliminated by use of two dimensional charts. The split screen capability of the system will permit two such charts to be displayed on one Monitor.

Several different systems of both the stroke-writing types and raster scan type have been compared for their cost effectiveness in the light of presently defined requirements.

The primary difference between these two types of systems lies in their resolution capabilities. Stroke-writing systems are available with resolutions of one part in one thousand or better. Raster scan systems are limited in their resolution by the scan frequency and associated system bandwidth:

Typical TV type raster scan CRT systems have resolutions of one part in 240 (or one part in 480 if the 2:1 interlace is not used for picture enhancement.) Increasing this resolution can only be accomplished by increasing the bandwidth of the system. A typical 525

line TV system has a bandwidth of approximately 6 mhz. Increasing the scan to 1000 lines per frame would require increasing the bandwidth to approximately 30 mhz., with associated increases in cost. However, for the SMS, a resolution of one part in 480 is acceptable.

### 3.2.2.1.1.2 Baseline CRT System Description

The system that has been chosen for the SMS baseline is the ADAGE/200 Graphic Display System. The ADAGE/200 is a low-cost, full graphic and alphanumeric clustered terminal system. The system contains a programmable Display List Processor as its central controller, which is capable of supporting multiple display stations. Each display station contains a 525-line TV display and a keyboard for data entry and control. A variety of communication options are available to interface the ADAGE/200 to a host computer, either directly or via telephone lines.

The Graphic Display System of the ADAGE/200 provides full general-purpose graphics and complete alphanumeric processing and display. It permits 16 terminals to be operated simultaneously and independently. Each terminal is equipped with its own memory, vector generator and symbol generator. A Display List Processor is the central control unit for the system. This processor accomplishes sophisticated text editing for each station without requiring any host computer intervention. The programmable nature of the Display List Processor eases the task of interfacing the system to a host computer and its operating system.

The ADAGE/200 Graphic Display System contains many special features to enhance its utility in a wide range of applications.

- . Full Graphics                      Vectors can be drawn on a 480 x 640 screen grid from any point to any other point.
- . Text Display                      Up to 2400 characters may be displayed on each display station, while 4000 can be held in memory.
- . Text Editing                      Powerful editing features such as insert/delete symbol, insert/delete text line, tab, etc.
- . Protected Data                      Data which cannot be erased from the keyboard by normal delete.
- . Non-destructive Cursors                      Unique cursors for graphics and for alphanumerics.
- . Paging                      Up to four separate pages of data can be retained and called up at each terminal.
- . Subpictures                      Up to 64 different images or messages may be defined in the terminal system and called by any terminal.



- . Blinking Data      Vectors and symbols can be programmed to blink.
- . Dashed Vectors      Vectors may be specified as solid or dashed.
- . Automatic Scissoring      Vectors defined to go off screen or come on screen are automatically scissored at the screen edge. Vectors which are defined completely off screen will not appear.
- . Vector Offset and Scale      Programmable registers provide automatic offset and scale of picture or picture elements.
- . TV Sync      TV Sync Signals are provided for synchronizing external devices.
- . Composite Pictures      The output from two channels can be connected together to drive a single display station thereby doubling the display content.
- . Program Function Keys      4 extra keys used for activating host computer programs.
- . Expandable Memory      Memory of the Display List Processor may be expanded to provide space for special function programs on subpictures.

### . Interfaces

Three types of interfaces are available, serial asynchronous, serial synchronous and parallel.

Each terminal has its own memory capable of holding 4000 characters. This is used to store symbols, vectors and control data. There are 2400 symbol locations on screen (30 lines of 80 symbols). Unused symbol locations do not require memory. Vectors occupy variable amounts of memory, depending on length and location. Control words are used to define blank screen areas, set operating modes and other control functions.

Graphics are defined on a 480 x 640 grid. Vectors may be drawn from any location on screen to any other location on screen. Up to a maximum of 50 screen widths of vector information may be stored in memory and drawn on screen.

Since memory can hold up to 4000 characters, it is possible to store more data than appears on screen at one time. Up to three alternate pages (where a page is equivalent to one screen area) can be used to store this additional data. An operator can rapidly move back and forth to these pages in one-half page steps.

The ADAGE/200 system can communicate to the host computer in serial asynchronous, serial synchronous, or parallel form.

The serial asynchronous interface uses ASCII code and is compatible with EIA Standard RS232C. It is compatible with Teletype

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format. Operating speeds of 300, 1200, 1800, and 2400 baud are available. Operating speed must be specified when ordering this interface.

The serial synchronous interface is compatible with IBM's Binary Synchronous Transmission. It is available in ASCII or EBCDIC and at operating speeds of 1200, 2400, and 4800 baud. Code and operating speed must be specified when ordering this interface.

A parallel interface is also offered with the system. This provides buffered data lines in or out, control lines, status lines and an interrupt line.

The ADAGE/200 is supplied with operational software to achieve the performance described.

In addition, two programs are supplied for host computer support. These are written in FORTRAN IV and supplied as a deck of punched cards. GRAF-PAC is a set of procedures designed to simplify for the user the process of implementing the display portion of his application programs. The subroutines which comprise the package give the user access to all control functions of the ADAGE/200 Graphic Display System and permit him to specify display of information using FORTRAN notation, without regard to the detailed hardware requirements.

Another program, PLOT-PAC, provides a system for automatic plotting of numerical data in rectangular, two-dimensional coordinates on an ADAGE/200 Display Terminal.

### 3.2.2.1.1.3 CRT Display System Operating Procedure

Alphanumeric or graphic data may be displayed on either of the CRT's at any position of the IOS at the option of the instructor,

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e.g., at any one instructor position, alphanumeric data may be displayed on both CRT's; graphic data on both; alphanumeric on one and graphic data on the other, or vice versa depending on the intelligence required on the training exercise.

The Keyboard/Display units will operate identically; the same displays will be available at each position, and the same keyboard action will be used at each position to select a display or modify a value stored in the computer. In addition, each CRT will be able to display and perform control actions independent of the other.

Each system keyboard has 69 keys as shown in Figure 3.2.2-2A. Besides standard typewriter keys, there are five keys for controlling the screen cursor (four arrow keys plus Home), four function keys (F1-F4), six edit and communication keys (2 ERASE keys, START MSG., LINE, CHAR., and SEND) and a CONTROL CODE key.

The typewriter keys act as normal typing keys, causing the symbol typed to replace the symbol at the cursor position. A Tab key provides both forward and backward tabbing. New Line moves the cursor to the left margin and down one text line.

The four arrow keys are auto-repeating and control the movement of the cursor on screen. The cursor may be displayed in either of two forms --an alphanumeric cursor and a graphic cursor-- and may be switched by the Switch Cursor key (shifted Home). The alphanumeric cursor is a blinking underline displayed at the bottom of a symbol position. The graphic cursor is a full-screen cross hair which may be

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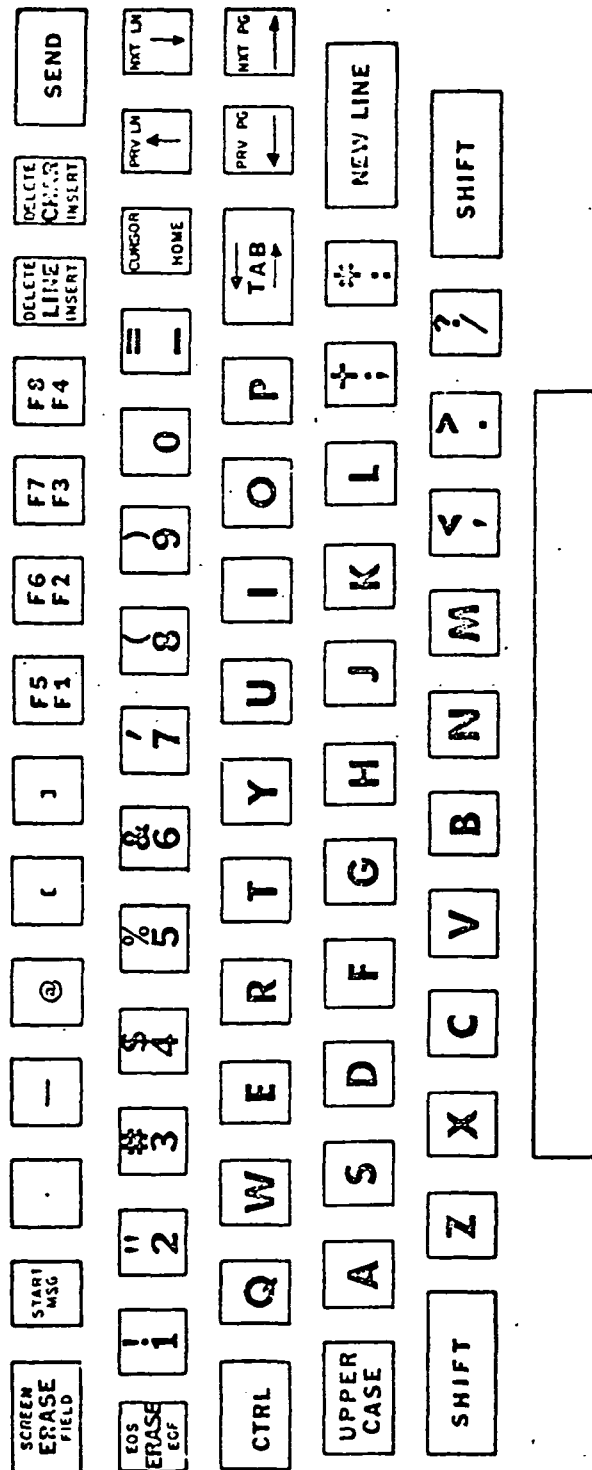


Figure 3.2.2-2A Keyboard Layout

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positioned at even numbered addressable locations in x and y. In upper case, these cursor control keys are used to scroll and change pages. The Home key causes the cursor to move to the upper left corner of the screen (first character position on first text line).

The four function keys each transmit to the host computer unique characters in upper and lower case (thus providing eight different codes). In addition, if the cursor is turned on, its location is sent as a character string following the function code.

The edit keys allow editing of text from the keyboard. The Insert Character Key causes all symbols from the cursor position to the right, through the end of the field, to be moved to the right one symbol position and a space to appear at the cursor position. The end of the field is defined to be the end of the line or, if there is protected data on the line, the location of the last unprotected character.

The Delete Character key deletes the symbol at the cursor position and closes in all symbols to the right, through the end of the field. The Insert Line key causes all lines from the cursor position to be moved down by one. The Delete Line key deletes the line on which the cursor rests, and moves all lines up by one. Erase EOF/EOS erases all symbols from the cursor position to the end of the field or end of screen respectively. Erase Field erases all symbols in the field. Erase Screen erases all text and vectors on the screen. None of these functions will alter protected data.

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Start Message is a communication control key which is used to define the beginning of a message if a message starts at other than the first character location of the viewable page. The SEND key causes alphanumeric data between the Start of Message and the cursor to be sent to the host computer.

The CONTROL key is provided for generation of additional ASCII codes which are useful for test and expansion purposes.

Also provided at each Station are four status indicator lights. These are:

Power            On when power is on.

Wait            On to indicate keyboard is disabled from Display List Processor. Blinking if no synch is being received from Display List Processor.

Error           On to indicate system or data error has occurred and has been communicated to host computer.

Program        Status is defined by host computer application program.

To take an action through the keyboard, the appropriate page will be selected by pressing the special function key F1 on the keyboard, and then typing in the one or two required page identifying characters followed by the "Send" key.

The line on the appropriate page will be selected by positioning the alphanumeric cursor to the first character in the

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desired line.

Backspacing can be used to correct entries. When the instructor verifies that the line is correct, he will press the "SEND" key which will replace the contents of the computer memory image of the line selected with the contents of the modified line.

Where a line contains more than one modifiable character, depression of the "TAB" key will cause the cursor to advance to the next modifiable character. Illegal actions, i.e., writing over labels will not be executed.

To clear a line that has been selected, of all instructor-inserted characters, and restore it to its previous condition, the "ERASE" function key will be depressed. When the simulator is reset from a "FREEZE" mode, the displays on the CRT will also be reset. Thus, all instructor insertions on all CRT pages will be cleared when the simulator is reset to a set of initial conditions.

The entire process - the formatting of displays, the means for display selection, and the selection of methods for taking actions using the keyboard has been human-engineered to make displays easy to select and to read, and to make control actions rapid and simple. The system described accomplishes needed actions with a few keystrokes, mnemonically coded to minimize human memory requirements.



3.2.2.1.2 CRT Display Pages

The following is a listing of CRT pages which will be provided:

- a. Event Time Monitor
- b. Panel Displays (excluding those provided by dedicated displays)
- c. Energy Management Predictor
- d. Malfunction Insertion and Display
- e. Circuit Breaker Status
- f. Crew Station Set-Up Verification
- g. Active Malfunctions and Tripped Circuit Breakers
- h. Mission Parameters and Summary Display
- i. Interface Data Stream and Telemetry Monitoring
- j. Enroute and Approach Display (including ILS/GCA)
- k. In-Flight Refueling \*
- l. External Environment
- m. Simulator Reset
- n. Simulator Status

\* not present Shuttle Baseline

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Each of the display categories will be identified by a one-or two-character mnemonic. The first character being a letter to identify the category, and the second character - when there is more than one page in the category - denoting the page within the category. To select a page, the instructor will press special function key F1 on the keyboard and then insert the one or two required characters through the normal typewriter keys.

The top line of the CRT will always contain the following items:

- a. A one-or two-character display mnemonic identifying the display.
- b. Symbols indicating the ground station in contact with the vehicle; if none are in contact, LOS (Loss of Signal) will be displayed.
- c. Mission elapsed time (MET).
- d. Simulated Greenwich mean time (GMT).

The top line of the CRT will be displayed as follows:

XX LOS

METXXX:XX:XX GMTTXXX:XX:XX

Space is available on the top line to the left of "MET" for computer generated alerts to the instructor informing him of events which may cause him to want to change the page or take other action.

#### 3.2.2.1.2.1 Event Time Monitor Page

A CRT located between the two instructors in normal practice will be dedicated to the Event Time Monitoring functions. The CRT will provide a

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chronological display of the most recent crew actions. The most recent crew action will be displayed on the top line of the CRT. As the next action takes place, it will occupy the first line, and the previous action will occupy the second. When the CRT page is filled, a new crew action will cause the last line on the page to be dropped from the display. Each line will contain the following data:

- a. The name of the control manipulated.
- b. The action taken: For a non-momentary switch, the new position will be displayed. For a momentary switch or continuous control, the direction of the most recent motion would be shown.
- c. The time at which the action occurred.
- d. The mnemonic of the panel page involved.

#### 3.2.2.1.2.2 Panel Display Pages

Panel display pages are basically repeaters of spacecraft control positions and displays. The panel displays will include all systems except those which are presented on dedicated displays. They also serve the function of parameter override (allowing the instructor to view a display other than the one present in the vehicle, and to view the true value of a display that has malfunctioned) and parallel switch operation (allowing the instructor to override the position of controls at the crew station). The repeater function enables the instructor to monitor trainee activities and to observe the reaction of the crew in rectifying errors and malfunctions and in performing their mission tasks. These displays will be displayed by panels as they appear in the crew station.

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Within each panel, there may be a number of display pages depending upon the number of controls and indicators available to the crew. Selection of the Panel Display through the keyboard will present a Panel Display Index to the instructor. The index will provide the instructor with the mnemonic of the particular panel desired. Selection of the desired panel display page will be accomplished using the procedure described in section 3.2.2.1.1.3. Panel pages will present to the instructor a display of the control and indicator positions presented in the cabin. Controls will be displayed as follows:

a. Continuous Controls. This type control will be displayed as a vertical rectangle. A scale will be located within the rectangle representing the range of the control. An index, also located within the rectangle will represent the present indication of the control. The control will be identified by its name.

b. Continuous Displays. This type of device is displayed in the same manner as Continuous Controls.

c. Switches. A tabular listing of system switches will be displayed. The listing will include the switch name and all available switch positions. The symbol(@) will be placed to the left of the switch position prevailing in the vehicle, an asterisk (\*) will be placed to the left of the position selected by the instructor for parallel switch operation, or, in the case of display selecting switches for parameter display override.

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d. Digital Displays. These displays will be presented in the same manner as in the vehicle. Commas, decimal points, and other symbols (e.g., N, S, E, W, +, -) will be appropriately displayed.

e. Quasi Digital Display (Flags). Display of this type will be accomplished by a special symbol.

#### 3.2.2.1.2.2.1 Parameter Display Override

Parameter display override will be usable in two different ways: (1) to view a display other than one present in the vehicle, and (2) to view the true value of a malfunctioned display. To accomplish the former, action will be taken at the representation of a switch position on the CRT; to accomplish the latter, action will be taken at the parameter display itself. All that will be required is to place an asterisk to the left of the switch position name in the first case, and to the left of the label of the display in the second case, using the same procedure described below for Parallel Switch Operation.

#### 3.2.2.1.2.2.2 Parallel Switch Operation

Placing an asterisk to the left of the name of a switch position selected by the instructor is all that is necessary to accomplish parallel switch operation. This will be done as follows. First, the CRT line containing the name of the desired switch position will be selected by locating the alphanumeric cursor. The cursor will be positioned at the first instructor-modifiable space or symbol. If this is not the space or symbol the instructor wishes to modify, he

will hit the "TAB" key. Each depression of which will move the cursor to the next instructor-modifiable space or character. Upon reaching the desired switch position, an asterisk will be typed in. Following this, the instructor will verify his action visually, and if correct, he will press the "SEND" key. This will establish parallel switch operation.

Parallel operation will be deleted by going through the same procedure, except that a blank space will be typed over the asterisk, rather than an asterisk over the blank space.

#### 3.2.2.1.2.3 Energy Management Predictor Display

This page will provide a graphic display of the critical parameters associated with energy management. The display will contain a symbol indicating the vehicle's current state and a second symbol which will predict the vehicle state. Predicted values of energy management parameters will be displayed in 30 second increments.

To select the Energy Management Predictor page, the instructor will use the page selection procedure previously described.

#### 3.2.2.1.2.4 Malfunction Insertion and Display

This feature will provide the instructor with the capability of entering malfunctions into any subsystem of the SSV and faults into the telemetry.

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To call up a malfunction, the instructor will first select the Malfunction Insertion and Display index page. This page is an index which categorizes malfunctions by system and the associated mnemonic for the system malfunction page. The instructor will then select the desired system malfunction page using the procedure previously described. The display page will contain a mix of discrete and variable malfunctions, one malfunction per line.

To insert a discrete malfunction, the line will be selected by locating the alphanumeric cursor at the appropriate line with the cursor at the third space. The instructor types in an asterisk in the position marked by the cursor. After visually verifying his action the instructor will press the "SEND" key. This will insert the malfunction into the system.

To enter or modify a variable malfunction, that line will again be selected by locating the alphanumeric cursor. For variable malfunctions, the range and its units are provided after the malfunction. When the malfunction is selected, cursor must be located two spaces after the last symbol. The instructor will type in the value of the variable malfunction above the cursor. After visually verifying his

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action, the instructor will press the "SEND" key, which will:

- a. Place an asterisk to the left of the malfunction listed on the page
- b. Add the value of the inserted malfunction to the right of the listed malfunction, and
- c. Introduce the variable malfunction into the system.

To modify a malfunction already in the simulator, the line will be selected as before. Since the first instructor-modifiable character will be the asterisk, the cursor will line up below it. Since the instructor wants to change rather than delete a malfunction he will press the "TAB" key to move the cursor to the next modifiable character, the previously inserted value of the variable malfunction. The instructor will then type over the previously inserted value with the new value he wishes to insert. Verification and insertion will be accomplished as described previously.

The presence of an asterisk to the immediate left of a listed malfunction indicates that malfunction is active. A quick scan will enable the instructor to locate any active malfunctions among those displayed on a page. To obtain a listing of all active malfunctions, the instructor would use the display of active malfunctions and tripped circuit breakers described in 3.2.2.1.2.7.



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3.2.2.1.2.5 Circuit Breaker Status

Tabular displays, organized by system by panel, will indicate for each circuit breaker its status: normal, permanently failed, temporarily failed or open. Using this display, the status of any circuit breaker can be changed to permanently failed or temporarily failed.

To call up the Circuit Breaker status display the instructor will use the procedure previously described. This action will display an index of the circuit breaker status pages and the mnemonic associated with each circuit breaker status page. Inserting the appropriate mnemonic and using keyboard procedure will cause the selected circuit breaker page to appear on the display. Panels containing more than 25 circuit breakers will require more than one page; panels containing fewer than ten will be grouped together on a single page.

The format of the display would appear as follows:

BC LOS  
LINECIRCUIT BREAKERMET 024:45:12 GMT 131:12:34  
PERM TEMP

123&lt;

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The "LINE" column would contain the line identifier. The "CIRCUIT BREAKER" column would contain a listing of the circuit breakers contained on a given panel. The status of the circuit breaker would be indicated by an asterisk in the appropriate column.

Four kinds of actions can be taken by the instructor with respect to circuit breakers: (1) permanently fail a circuit breaker, (2) temporarily fail a circuit breaker, (3) change from permanently failed to temporarily failed, and (4) change from temporarily failed to permanently failed. Each of these actions is accomplished by replacing an asterisk in the "PERM" or "TEMP" column with a blank space, replacing a blank space with an asterisk or both. This is accomplished in the following manner.

a. The line containing the circuit breaker whose status is to be changed is selected by locating the alphanumeric cursor at the first modifiable character of the line.

b. The instructor types in an asterisk if he wishes to insert a permanent failure or change the failure from the temporary to permanent. If the latter, the asterisk in the "TEMP" column is erased when the one in the "PERM" column is typed in. If he wishes to change a failure from temporary to permanent, he types in a blank, erasing the asterisk.

c. If the instructor wishes to insert a temporary malfunction in an operating circuit breaker, he hits the "TAB" key, which

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moves the cursor to the "TEMP" column, and then types the asterisk there. When the cursor is in the "TEMP" column, a temporary failure can be changed to a permanent one by typing over the asterisk with a blank, thus moving the asterisk to the "PERM" column. Circuit breakers, cannot, of course, be reset from the instructor's station.

d. Following modification of the line, the instructor verifies his action, and if correct, presses the "SEND" key.

#### 3.2.2.1.2.6 Crew Station Setup Verification Display

The purpose of the crew station setup verification display will be to enable the instructor to rapidly verify, prior to initiating an exercise at a reset point, that the crew controls are in their proper position. To call up this display, the instructor will use the page select procedure, with a two letter mnemonic. The first letter will identify the crew station setup verification display and the second letter will correspond to one of the 20 reset points at which the simulator can be initialized by activating a reset.

The display will contain three columns, headed "CONTROL", "DESIRED POSITION", and "ACTUAL POSITION". The names of up to 25 controls whose desired and actual position differ will be displayed, along with the desired and actual positions. The format of the display would appear as follows:

VC LOS  
CONTROL

MET 024:45:12 GMT 131:12:34  
DESIRED POSITION ACTUAL POSITION

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Since this display will normally be used when resetting to one of the reset points, it will be automatically called up to one of these 20 points using the procedures described in 3.2.2.1.2.16. If more than 25 controls are not in their desired positions, the line below that for the 25th control will contain a legend appraising the instructor of that fact. Since the circuit breaker status will be displayed elsewhere, one line of the display will be reserved for a summary of circuit breaker status. The appearance of the legend "CIRCUIT BREAKER" will indicate that one or more of the circuit breakers in the vehicle should be reset or tripped. Their identity can be determined by reference to the display of active circuit breakers described in 3.2.2.1.2.7.

#### 3.2.2.1.2.7 Active Malfunctions and Tripped Circuit Breakers

This display will provide, in one place, a listing of all active malfunctions and tripped circuit breakers. Using it, the instructor will be able to clear malfunctions individually or simultaneously. This display will contain all the lines in the malfunction and circuit breaker displays that have an asterisk in them, that is, all active malfunctions, discrete or variable, and all tripped circuit breakers: those permanently failed by the instructor, and those temporarily failed by the instructor. The instructor will be able to delete a malfunction or modify a variable malfunction with the display in the same manner as with the regular malfunction displays, but he will not be able to insert a malfunction with it, since only active malfunctions will be

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displayed. In a similar manner, the instructor will be able to change the status of a previously failed circuit breaker from permanently failed to temporarily failed, or vice versa. He will not be able to fail untripped circuit breakers with this display since only tripped circuit breakers will be indicated.

The last line on the page will be labeled "CLEAR PAGE". When this line is selected and inserted, all malfunctions will be cleared, and all circuit breakers will be made resettable.

#### 3.2.2.1.2.8 Mission Parameters and Summary Display

This page will provide a one-page summary of critical mission parameters. The parameters will be changed as required for the various mission phases.

The display will provide, in one place, a summary of (TBD) critical parameters during a given phase of the mission. It will be selected using the standard procedure, and a two letter mnemonic. The first letter will denote the Mission Parameters Summary display, and the second letter will identify the mission phase that begins at one of the 20 reset points provided. As the mission progresses, and different parameters become important, the items on the display page will be changed accordingly.

The format of the display will be as follows: each line will contain the name of the parameter, its value, and the units in which the value is expressed. Since this will be an information only display, no line identifiers will be necessary.

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3.2.2.1.2.9 Interface Data Stream and Telemetry Monitoring

This display will permit the values of any interface data stream Command Data or Telemetry Subsystem parameters to be monitored. Telemetry faults can be inserted into any channel and both faulted and true values can be monitored. The CRT pages used for interface data stream will be organized as follows:

- a. Uplink Command Input
- b. Uplink Command Summary
- c. Telemetry Monitoring
- d. Telemetry Malfunction Insertion

3.2.2.1.2.9.1 Uplink Command Input Page (UCIP)

This page will provide the capability for an instructor to insert uplink commands into the training exercise while the simulator is running independently or while integrated with MCC. The command entries into the CRT will be designed in such a manner to be compatible with the mission uplink command documentation - i.e., the decimal, octal or alphanumeric classification system used by NR/NASA to catalogue the commands will be used by the instructor in the operation of this page to identify the commands to be inserted. The page will be formatted in such a manner that all entries required for the various types of commands as displayed on the page are line selectable. The format, units, and number of characters required for each entry will also be defined in the display format.

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The last command entered for each type command will be displayed in the input field. This display will appear on all UCI pages which are being displayed on CRT's regardless of the one from which the command originated.

An error message will be generated for illegal entries and remain for a period of ten seconds.

An override capability will be provided to enable commands from the IOS to be processed regardless of the power configuration and/or signal strengths. The instructor will be able to select or cancel the override by line input. Incorrect or garbled commands will be displayed in a different format, e.g., hexadecimal.

3.2.2.1.2.9.2 Uplink Command Summary Page

A command summary page will be provided which will display the following data for each command entered during a training session:

- a. The code name for the command
- b. Status of the command (e.g., executed, ignored, in-process)
- c. The vehicle uplink system, if redundant or multiple units are on-board, to which the command was addressed.
- d. Originator of the command (MCC, UCIP or any other system capable of inserting uplink commands)
- e. The GMT that the command was received in the simulated vehicle.

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Incorrect or garbled commands will be displayed in a different code format, e.g., hexadecimal.

All commands will be recorded and available for display on the Uplink Command Summary page regardless of whether the page is active on the CRT at the time the command(s) were entered.

3.2.2.1.2.9.3 Telemetry Monitoring Page

Sequential pages will be provided which will display and monitor all telemetry parameters organized by SSV systems. The telemetry data displayed will repeat the parameter values which are being transmitted to the down-link equipment by the simulated vehicle system programs as modified by the malfunctions inserted in the bit stream pattern through the Telemetry Malfunction Page (TMAL). The parameters will be identified by their TM number and descriptive engineering terminology. The values of analog parameters will be displayed in terms of the engineering units used by the simulator programs, i.e., degrees -Rankine, volts, amps, pounds per square inch, etc. The values of discrete parameters may be displayed as on/off, 1 or 0, primary or secondary, etc.

3.2.2.1.2.9.4 Telemetry Malfunction Insertion Page

This page will enable the instructor to insert up to 25 malfunctions into the telemetry down-link data. The page will be formatted in such a manner that each malfunction entered is tabulated in the order of insertion, and the following data associated with each



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malfunction measurement is displayed:

- a. Telemetry measurement number
- b. Actual value (in engineering units)
- c. Failed value
- d. Type of malfunction
- e. Malfunction value

The types of malfunctions which may be entered are as follows:

- a. Static integer/discrete
- b. Static bit pattern
- c. Drift malfunction
- d. Offset Malfunction
- e. Fixed value malfunction

The instructor entry operations will be designed so that the allowable and required entries are annotated on the scratch pad line. Error messages will be provided to inform the instructor of illegal operations.

### 3.2.2.1.2.10 Enroute and Approach Display

The enroute and approach display will provide the following types of horizontal profile flight paths depending on the mode of operation:

- . Enroute Display
- . Approach Display

The display will automatically switch to or from the approach mode when the vehicle position crosses a predetermined boundary for a selected approach area. The display will portray a solid line plot denoting the programmed mission or maneuver and a dashed line will represent the vehicle's path with an aircraft symbol representing the trainee's instantaneous position.

#### 3.2.2.1.2.10.1 Enroute Mode

The enroute mode will provide the instructor with a graphic presentation of the vehicle's flight path in relation to the desired flight path. This graphic presentation will be provided for atmospheric (ferry) flights.

The instructor will be presented a graphic display of the vehicle's ground track compared with the desired ground track. The display will provide a graphic representation, in terms of circles, call letters and channel or frequency of all surface facilities within the area of display.

The enroute mode will operate at continuously variable scales from 1 inch equals 10 nautical miles to 1 inch equals 50 nautical miles as selected from the instructor's control panel. The control will be graduated in 0.1 nautical mile increments and incorporate a positive lock to prevent inadvertant movement.

#### 3.2.2.1.2.10.2 Approach Mode

The approach mode will present a magnified display of the course flown in the approach area with respect to a simulated navigation facility normally located at the center of the chart. The display can then be selected:

a. Manually by setting in the identification code of the surface facility on the "AIRPORT CHART SELECT" and by depressing the "APPROACH" switch light on the instructor's console.

b. Automatically, by the simulated aircraft approaching within 30 nautical miles range of the tuned surface facility. As the 30 nautical mile range is exceeded, the display will automatically switch to the previous enroute display.

In the approach mode, the provision will be made to

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vary the scale of the display from 1 inch equals 0.2 nautical miles to 1 inch equals 10 nautical miles as selected by the instructor from his Graphics Mode control panel. The control will be graduated in 0.1 mile increments and incorporate a positive lock to prevent inadvertent movement. The simulated facility will be located at the center of the display together with the station call letters and channel or frequency.

As the vehicle approaches to within ten nautical miles from the airport, the display is automatically switched to a terminal mode. In this mode, a split screen display is presented. The upper display will provide an elevation versus range to touchdown point along an axis representing ten miles in length; the lower display presents azimuth versus range to the touchdown point. The displayed runway heading and glideslope will be defined by the surface facility selected by the instructor.

Additional data required for ILS or GCA operations during the approach or landing phase of a Ferry Mission, when the instructor is acting in the roll of a ground controller, will also be displayed. This data includes glide slope deviation, range, heading, airspeed, localizer deviation, and frequency of the landing aid. Insertion of frequency into the training problem is commanded through the CRT Keyboard.

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### 3.2.2.1.2.11 In-Flight Refueling Page \*

In flight refueling is associated with the Ferry phase of the SSV mission. The in-flight refueling phase of this mission will be simulated to a limited extent. A visual scene for rendezvous and hook-up with the tanker aircraft will not be simulated. However, the effects of on-loading fuel from the tanker will be part of the simulator program (e.g., increase in the fuel quantity gauges for the ABES at a constant rate, change in the vehicle's CG as the fuel load increases). The instructor will be provided with a CRT page for controlling the in-flight refueling program. A fuel quantity will be displayed to appraise the instructor of the progress of the refueling operation.

### 3.2.2.1.2.12 External Environment

This page will contain a listing of the following environmental parameters for resets to aerodynamic mission phases.

- a. Wind direction and speed
- b. Altimeter setting
- c. Outside air temperature
- d. Rough air intensity
- e. Cloud base and top
- f. Visibility

A similar list of resettable parameters will be developed for other mission phases.

\* Currently not a Shuttle requirement.

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To call up this page, the instructor will use the standard page selection procedure and the mnemonic identifying the External Environment page. To insert an environmental condition, the line will be selected by locating the cursor at the desired line and activating the tab key. The cursor will appear in the next space after the environmental parameter. The instructor types in the value of the parameter he wishes to enter. After verifying his entry, the instructor depresses the "SEND" key which will insert the parameter value into the system.

To change an environmental value already in the simulator, the line will be selected as before. The cursor will be located under the first number of the present value. The instructor will type over the previously inserted value with the new value he wishes to insert. Verification and insertion will be as described above.

#### 3.2.2.1.2.12.1 Wind Direction and Speed

It will be possible for the instructor to introduce any wind speed from 0 to 200 knots and any wind direction through 360 degrees. The wind velocity applied will affect the course flown and will produce a correct drift angle and ground speed. Takeoff characteristics, aerodynamic characteristics, and build-up/drop-off rate for airspeed will properly reflect the aircraft performance when the aircraft is subject to the same environment.

#### 3.2.2.1.2.12.2 Altimeter Setting

The instructor will be able to adjust the altitude

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system to reflect any barometric pressure setting value from 28 through 32 inches of mercury in increments of 0.01 inch. Adjustment of the altimeter setting control will affect the indicated altitude according to standard pressure altitude relationship charts.

#### 3.2.2.1.2.12.3 Outside Air Temperature

The capability to vary outside air temperature from -50°C to +50°C will be provided to the instructor. Variations from normal will appropriately affect engine thrust and takeoff characteristics. Installation and compressibility errors will be included.

#### 3.2.2.1.2.12.4 Rough Air Intensity

The instructor will be able to control the intensity of simulated rough air conditions. Rough air will be entered through numerical values ranging from 0 (calm) through 10 (intense) in single digits. The effects of rough air introduced will appropriately be reflected in affecting instruments, controls, visual and motion systems. The rough air control will be functional at all airspeeds associated with atmospheric flight.

#### 3.2.2.1.2.12.5 Cloud Base and Top

The instructor will be provided the capability of determining the base of the cloud layer, and the thickness of the layer, which will be reflected in the visual scene. The cloud layer base will be variable from 100 ft. to 50,000 ft. The tops of the cloud layer will be varied from 2000 ft. to 60,000 ft.



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### 3.2.2.1.2.12.6 Visibility

The instructor will be able to introduce visibility into the visual scene from the IOS. The instructor may be able to vary the visibility from 0 nautical miles to 55 nautical miles in any increment.

### 3.2.2.1.2.12 Simulator Reset

The system will permit the problem to be easily started at one of the 20 reset points, a safe store point, or a write-reset point using controls located on the Operate Control Panel. The initial conditions for the start of simulator operation can be set in four ways:

- a. To one of the 20 reset points stored in the computer. One of these reset points would be for the beginning of the mission.
- b. At any of the "SAFE STORE" points previously selected by using the "SAFE STORE" switch.
- c. At any one of the "WRITE-RESET" points stored in the computer.
- d. In "STEP-AHEAD" mode which moves the simulator in either direction a preselected increment of time at a rapid rate.

To set or reset the simulator for the start of operation from one of the 20 reset points, from a safe store point, or from a write-reset point, the instructor will first call up the Simulator Reset page by depressing the "RESET" switch light on the Operate Control panel. The display on this page will contain the following lines, each with an identifier:

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- a. Twenty lines with the name of 20 reset points
- b. One line labeled "SAFE STORE"
- c. One line labeled "WRITE-RESET"

To reset the simulator, the appropriate line will be selected by locating the alpha numeric cursor at the first character of the desired line.

For resetting to one of the 20 reset points, the "SEND" key will then be depressed, completing the needed action. For resetting to one of the points previously selected by the time of depression of the "WRITE-RESET" switch, the reference number of that write-reset point, assigned by the computer must be inserted; this will be done by typing it in on the Write-Reset line in an appropriately marked space.

For "SAFE STORE", a mission elapsed time must be inserted before the "SEND" key is depressed, by typing the desired time in appropriately marked spaces on the line.

#### 3.2.2.1.2.14 Simulator Status

This page will assist the instructor or operator in performing a "morning readiness check" of the simulator. This program will enable the operating personnel to determine if the simulator is ready for operation. The check will utilize automatic sequencing through a series of standard static outputs utilizing the normal iteration rate of the simulator program. These tests will enable the operator to visually ascertain that the subsystems - visual, DCE,

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computer motion base and sound - are operating properly.

To select this function, the instructor/operator will use the standard page selection procedure and the appropriate keys associated with the mnemonic identifying the Simulator Status page. Insertion of these data will cause the computer to step through the simulator diagnostic program incrementally. The data provided on the CRT page will permit the instructor/operator to visually verify the desired output at each step. The program will require approximately 30 minutes of running time.

### 3.2.2.1.3 Dedicated Displays

The following dedicated displays, repeaters of crew station instruments, and control position indicators, will be provided and located on the upper canted sector of the center portion of the IOS.

#### 3.2.2.1.3.1 Repeater Instruments

The following repeater instruments located at the IOS will accurately duplicate the readings or indications of their counterpart located in the crew cabin.

These instruments will be grouped in a configuration similar to the arrangement on the vehicle's instrument panel. The section of the console reserved for the dedicated instruments is divided between the two instructor positions.

- a. Caution and Warning Indicators
- b. Monitor, Left CRT
- c. Monitor, Center CRT
- d. Flight Director Attitude Indicator (Commander)
- e. Vertical Speed Indicator (Commander)
- f. Barometric Pressure Altimeter (Commander)
- g. Airspeed/Mach Number Indicator (Commander)
- h. Acceleration Indicator (Commander)
- i. Horizontal Situation Indicator (Commander)
- j. Elapsed Time Meter (Commander)
- k. Gimbal Position Indicator

- l. Monitor, Right CRT
- m. Monitor, PMS CRT
- n. Flight Director Attitude Indicator (Pilot)
- o. Vertical Speed Indicator (Pilot)
- p. Barometric Pressure Altimeter (Pilot)
- q. Airspeed/Mach Number Indicator (Pilot)
- r. Rendezvous Radar
- s. Acceleration Indicator (Pilot)
- t. Horizontal Situation Indicator (Pilot)
- u. True Airspeed/Static Air Temperature Indicator
- v. Elapsed Time Meter (Pilot)
- w. Rudder Position Indicator
- x. Elevon Position Indicator

#### 3.2.2.1.3.2 Hand Controller Indicator Panel

The Hand Controller Indicator consists of a series of tell-tale lights and analog displays which inform the instructor of hand controller activity (Reference Figure 3.2.2-3). Three lights are provided to indicate the location at which the hand controller is being operated: "CDR" - Commander's Station, "P" - Pilot Station, "OMS" - Orbit Maneuvering Station. Six tell-tale lights provide the following positions of the translational hand controller:

- a. + X or - X
- b. + Y or - Y
- c. + Z or - Z

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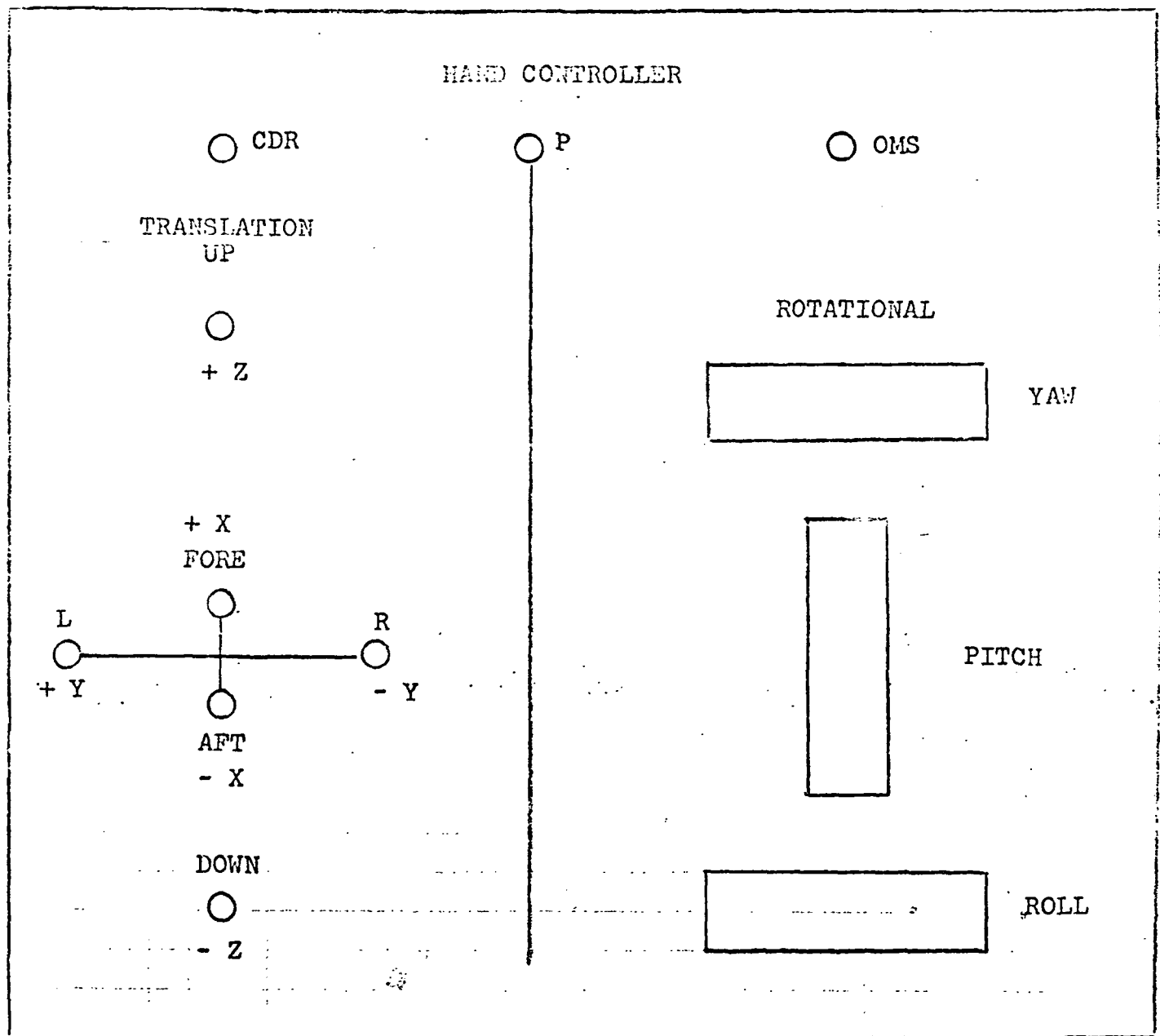
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Three center-zero analog meters will indicate the  
directions of the rotational hand controller:

- a. Positive or negative pitch
- b. Positive or negative yaw
- c. Positive roll or negative roll



HAND CONTROLLER INDICATOR PANEL

FIGURE 3.2.2-3

|               |  |                   |
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### 3.2.2.1.4 Instructor Station Controls

The instructor will be provided controls at his console for those functions not accomplished through the CRT display system. Since the IOS is designed to provide the flexibility of one or two instructor operation depending on the training exercise, some control panels are duplicated at the Commander and Pilot instructor station. Control panels which are conveniently accessible to both instructors are not repeated. Control panels at both instructor locations are arranged so that those most frequently used are conveniently located for efficient operation. The following panels are located on the IOS. The number following the panel name indicates the number of panels provided.

- a. Simulator Status (1)
- b. Operate Control (1)
- c. Record/Playback (2)
- d. Communications Control (2)
- e. Lighting/Sound Control (2)
- f. Graphic Control (2)
- g. Monitor Select (2)
- h. Speaker Panel (1)

#### 3.2.2.1.4.1 Simulator Status Panel

The Simulator Status Panel provides a visual indication to the instructor of the status of the simulator and its associated subsystems. (Reference Figure 3.2.2-4. This panel is located in a central location on the IOS console to facilitate convenient access and ease of operation by either instructor. The panel is comprised of



two sections. One section contains indicators denoting the status of the visual system; the other section contains indicators which present the status of power, DCE, computer, and motion system.

#### Visual System Status

"MIP" - Illumination of this indicator denotes that maintenance is in progress on the system.

Indicators are provided which, when illuminated, denote that the visual scene for that vehicle window is ready to be portrayed. In the MBCS, the bank of indicators represent the forward cabin windows and are designated as follows:

"LS" - Left side

"LQ" - Left quarter

"LF" - Left forward

"RF" - Right forward

"RQ" - Right quarter

"RS" - Right side

The status of the image generators is denoted by ten indicators. When illuminated, the indicator signifies that the appropriate image generator is operational. Since the image generators have not been completely defined at this time, the indicators have not been labeled. Each indicator will represent an individual image generator.

#### Power System Status

"MIP" - This indicator, when illuminated, represents that maintenance is in progress.

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| SIMULATOR STATUS |    |    |          |       |    |
|------------------|----|----|----------|-------|----|
| VISUAL           |    |    | POWER    |       |    |
| MIP              |    |    | MIP      | ON    |    |
| WINDOWS FORWARD  |    |    | DCE      |       |    |
| LS               | LQ | LF | RF       | RQ    | RF |
| IMAGE GENERATORS |    |    | COMPUTER |       |    |
|                  |    |    | FAULT    | READY |    |
|                  |    |    | MOTION   |       |    |
|                  |    |    | MIP      |       |    |

FIGURE 3.2.2-4  
MBCS SIMULATOR STATUS PANEL

"ON" - When all required power from the main power source is available to the simulator for its operation, this indicator will illuminate.

#### DCE Status

"READY" - Illumination of this indicator denotes that the DCE unit is tied into the simulator and READY for operation.

#### Computer Status

"FAULT" - The computer fault light will indicate when a fault has been detected. When the source of the fault is removed, the light will be extinguished. If the fault is transient, the light will not stay on. The computer fault indicator is only active when the computer is off-line and when not operating in a mission mode.

"READY" - This indicator, when illuminated, signifies that the computer is tied into the simulator and the simulator is READY for operation.

#### Motion Status

"MIP" - This indicator, when illuminated, informs the instructor that maintenance is in progress on the motion system.

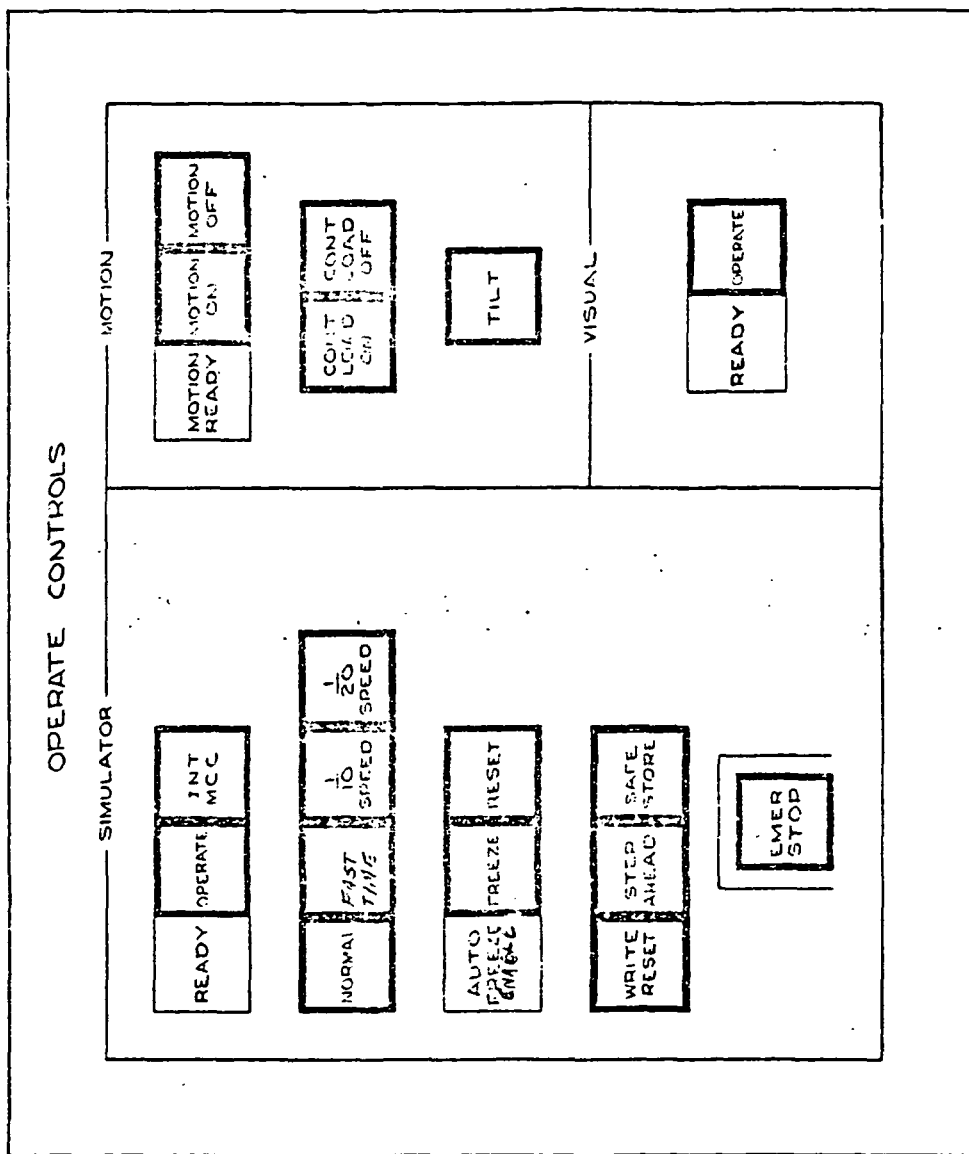
#### 3.2.2.1.4.2 Operate Control Panel (Reference Figure 3.2.2-5)

The Operate Control Panel contains all the necessary controls and indicators for the safe operation of the simulator and its subsystems. The panel is located in a central position of the IOS to permit convenient access and ease of operation by either instructor.

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OPERATE CONTROL PANEL

FIGURE  
3.2.2-5

|                 |  |                   |
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The panel is divided into three sections each of which contains the controls and indicators peculiar to that simulator function. The sections are titled: SIMULATOR, MOTION and VISUAL.

#### Simulator Control Panel

The following are the indicators and controls located on the Simulator Control Panel and a brief description of their function.

"READY" - This indicator illuminates when the simulator and the computer and ancillary equipment are ready for simulator operation.

"OPERATE" - This switch-light when activated will unfreeze the simulator, causing it to resume operation from the point at which it was frozen.

"INT MCC" - This is a dual action switch-light. When first depressed, the light illuminates and integrates Mission Control Center into the training exercise. A second depression of the switch deactivates this mode, and the light is extinguished.

"NORMAL", "FAST TIME", "1/10 SPEED", "1/20 SPEED" - These four dual action switch-lights when engaged separately will control the speed at which the training exercise is presented to the trainee. In the NORMAL mode the exercise is presented in real time. The remaining switches permit the instructor to present the training problem in the fast time mode or the selectable fractional parts of real time as indicated on the switch-light.

"AUTO FREEZE ENABLE" - When this light is activated, the simulator is automatically stopped when any of the preselected simulator parameters have been exceeded.

"FREEZE" - Activation of this switch-light causes the computer to enter the freeze mode. In the freeze mode, integration and time varying functions will be held constant.

"RESET" - This switch-light is activated to initialize the simulator to a specific set of initial conditions. The conditions are such that from reset, consumables, switch positions, on-board computer modes and trajectory characteristics are representative of the mission planning documentation. Upon activation of the "RESET" switch-light, the reset condition will be displayed on the CRT and the instructor will have the option of changing parameters through the CRT keyboard. Activation of the simulator from the "RESET" mode will be accomplished by activation of the 'Operate' switch.

"WRITE-RESET" - Activation of this switch-light permits the instructor to store, without interrupting the real-time simulation, those values in memory which are required to reinitialize the simulator back to that point.

"STEP-AHEAD" - Activation of the switch-light allows the instructor to advance or retard the training exercise by a pre-selected amount of time. During this mode, the computer will execute the program in faster than real time. The reset point will be selected

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as follows: Upon depression of the "STEP-AHEAD" switch, the following will be displayed on the scratch pad line of the CRT:

GMT \_\_\_\_\_

The cursor will be positioned after GMT. The instructor will enter the GMT of the position he desires to place the simulator. "STEP-AHEAD" will be executed when the "SEND" key is depressed.

"SAFE STORE" - This switch-light, when activated will cause the simulator to store, once every minute, without interfering with real-time simulation, those values in memory, including all active malfunctions, which are required to subsequently initialize the simulator back to that point. This storage will provide an intermediate point to which a problem can be re-initialized by use of the "RESET" control.

"EMERGENCY STOP" - This red switch-light, when activated, will result in removal of all primary power from the simulator with the exception of 115-volt, 60-hertz utility power. The switch shall be capped and a 3/16-inch red border will surround this switch-light. On the motion-base simulator IOS, this switch-light will also remove all power from the motion system and return the motion platform to the stowed position.

Motion Control Panel. This panel, as described below, applies only to the IOS for the motion-base simulator.

"MOTION READY" - Illumination of this lamp indicates that the motion system is prepared to be activated.

"MOTION ON" - This switch-light is depressed to operate the motion system. This switch is inoperable until the READY light is illuminated.

"MOTION OFF" - This switch-light deactivates the motion system from the simulator and returns the motion platform to the stored position.

"CONT LOAD ON", "CONT LOAD OFF" - These two switch-lights control the power to the control loading system.

"TILT" - Activation of this switch-light rotates the motion platform to the launch attitude.

#### Visual Control Panel

"READY" - This light illuminates when the visual system is available for activation.

"OPERATE" - This dual function switch-light is activated to present the forward station visual scene to the simulator cabin. This switch-light is inactive until the READY light is illuminated. A second depression of this switch deactivates the visual scene.



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3.2.2.1.4.3 Record/Playback Panel

These controls, in conjunction with the keyboard are used to record the trainee's performance for the prior ten minutes and play it back (Reference Figure 3.2.2-6). The following controls are located at the IOS.

"OPERATE" - The switch-light, when activated permits either the record or playback mode to commence.

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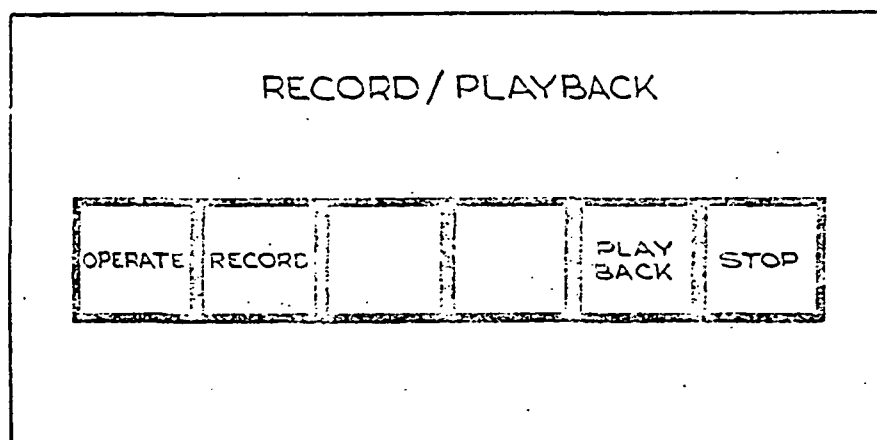
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RECORD / PLAYBACK PANEL

FIGURE 3.2.2-6

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"RECORD" - Activation of this switch-light permits the system to commence recording, in real-time, the trainee's actions in controlling the simulated vehicle.

"PLAYBACK" - This switch-light when activated permits the instructor to replay the trainee's recorded performance.

"STOP" - This switch-light deactivates the record/playback software system.

3.2.2.1.4.4 Communications Control Panel

This panel contains the controls necessary for the instructor to communicate with the trainee, other instructors and personnel in support of the training program (Reference Figure 3.2.2-7).

Two sets of switch lights will be provided to enable the instructor to talk and listen on specified networks (The Active Net) or to simply monitor conversation on one or more networks, (The Monitor Nets).

Each set of switches will provide control of the networks as follows:

- VHF-1 These three switch lights permit the
- VHF-2 instructor to act in the roll of a ground
- S-Band station operator when the appropriate
- switch light is depressed.
- ICS Activating this switch ties the instructor
- into the crew station interphone circuit.

The following switches enable six independent channels for communication between the SMS instructors, and the crew station as follows:

- a) AL-CS Instructor to Commander Work Station
- b) AL-LS Instructor to Pilot Work Station
- c) AL-MSS Instructor to Mission Specialist  
Work Station
- d) AL-PS Instructor to Payload Specialist  
158< Work Station

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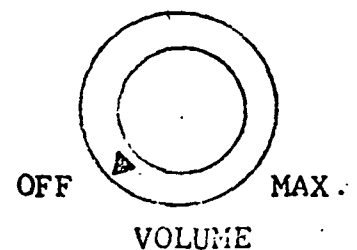
## INSTRUCTOR COMM

- ACTIVE NET -

|             |             |             |          |            |          |  |
|-------------|-------------|-------------|----------|------------|----------|--|
| VHF 1       | VHF 2       | S-BAND      | ICS      |            |          |  |
| AL<br>CS    | AL<br>LS    | AL<br>MSS   | AL<br>PS | AL<br>MS   | AL<br>ZR |  |
| MAINT.<br>1 | MAINT.<br>2 | MAINT.<br>3 | SM       | SMS<br>TLM |          |  |

|             |             |             |          |            |          |      |
|-------------|-------------|-------------|----------|------------|----------|------|
| VHF 1       | VHF 2       | S-BAND      | ICS      |            |          |      |
| AL<br>CS    | AL<br>LS    | AL<br>MSS   | AL<br>PS | AL<br>MS   | AL<br>ZR |      |
| MAINT.<br>1 | MAINT.<br>2 | MAINT.<br>3 | SM       | SMS<br>TLM | FD       | GOSS |

HEADSET JACKS

FIGURE 3.2.2-7  
COMMUNICATIONS PANEL

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e) AL-MS Instructor to Manipulator Work  
Station

f) AL-ZR Instructor to Z-Axis Rendezvous  
Work Station

Maint-1 When depressed, these switches enable the  
Maint-2 instructor to communicate on up to three inde-  
Maint-3 pendent Maintenance interphone networks to the  
maintenance locations within the simulator  
complex. These networks operate independent  
of simulator power.

SM This switch enables the Simulation Coordination  
Loop between the SMS and MCC instructors

FD This switch allows a monitor-only capability  
of the Flight Director Loop.

GOSS This switch allows a monitor-only capability of  
the GOSS (Ground Operation Support System) Loop

SMS/TLM Selection of these switches allows independent  
talk-listen or monitor of the Telemetry Loop.

Headset  
Jacks Headset jacks are provided for the instructor  
and four observers

Headset  
Volume This control permits the sound intensity of the  
headset(s) to be varied

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#### 3.2.2.1.4.5 Lighting/Sound Control Panel (Reference Figure 3.2.2-8)

"VOLUME" - This control permits the instructor to vary the intensity of the vehicle's sounds. The "NORMAL" position is clearly identified.

"SOUND ON" - This dual action switch-light allows the sound system to be activated and deactivated.

"CONSOLE" - This control permits the instructor to vary the intensity of the console lighting.

"INDICATOR" - This control permits the intensity of the indicator lights and switch lights on the instructor panel to be varied.

"L. IND LAMP TEST", "R. IND LAMP TEST" - Activation of these momentary push button switches will illuminate indicator lamps and switch lamps on the instructor panel. One switch will test the left portion of the console; the other will test the right portion. Burned out lamps can be easily replaced from the front of the panel without special tools.

#### 3.2.2.1.4.6 Graphic Control Panel

This panel provides the instructor with the capability to control the presentation on the graphic display and on the visual monitor (Reference Figure 3.2.2-9). The following is a description of the function of the controls.

"ENROUTE" - This switch-light, when activated, presents on the graphic display the ground track of the aircraft.

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"APPROACH" - Activation of this switch-light presents magnified display of the course flown in the approach area with respect to a simulated navigation facility.

"ENROUTE SCALE" - This control consists of three thumb wheel knobs by which the instructor can vary the scale of the Enroute and Approach displays. The scale is variable from one inch equals 0.2 nautical mile to one inch equals 50 nautical miles. The scale may be changed in 0.1 nautical mile increments, and incorporates a positive lock to prevent inadvertent movement.

"AIRPORT CHART SELECT" - This control consists of two thumb-wheel knobs which select a preprogrammed airport approach chart to be displayed on the graphic CRT. The number of airport approach charts to be in inventory is TBD.

"AIRCRAFT CHART CENTER" - Activation of this switch-light places the vehicle in the center of the display.

"AIRPORT CHART CENTER" - This switch-light when activated permits the instructor to place the airport in the center of the display.



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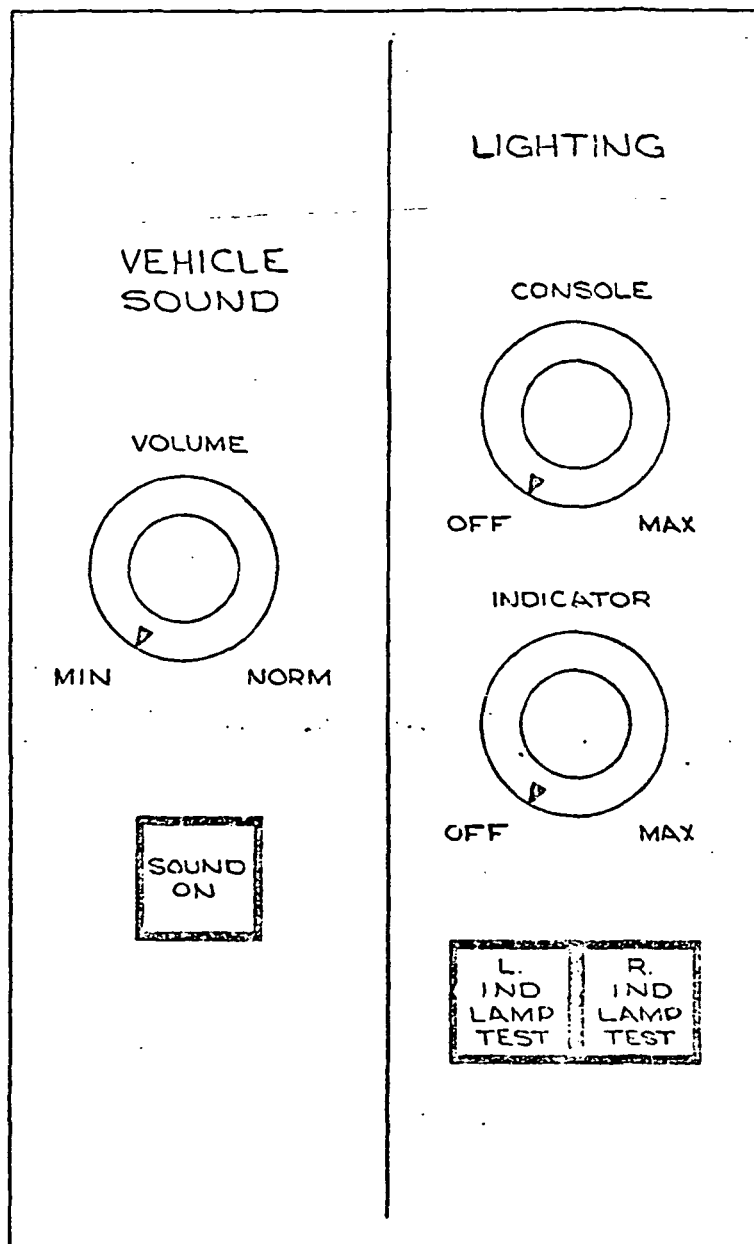
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LIGHTING/SOUND PANEL

FIGURE 3.2.2-8

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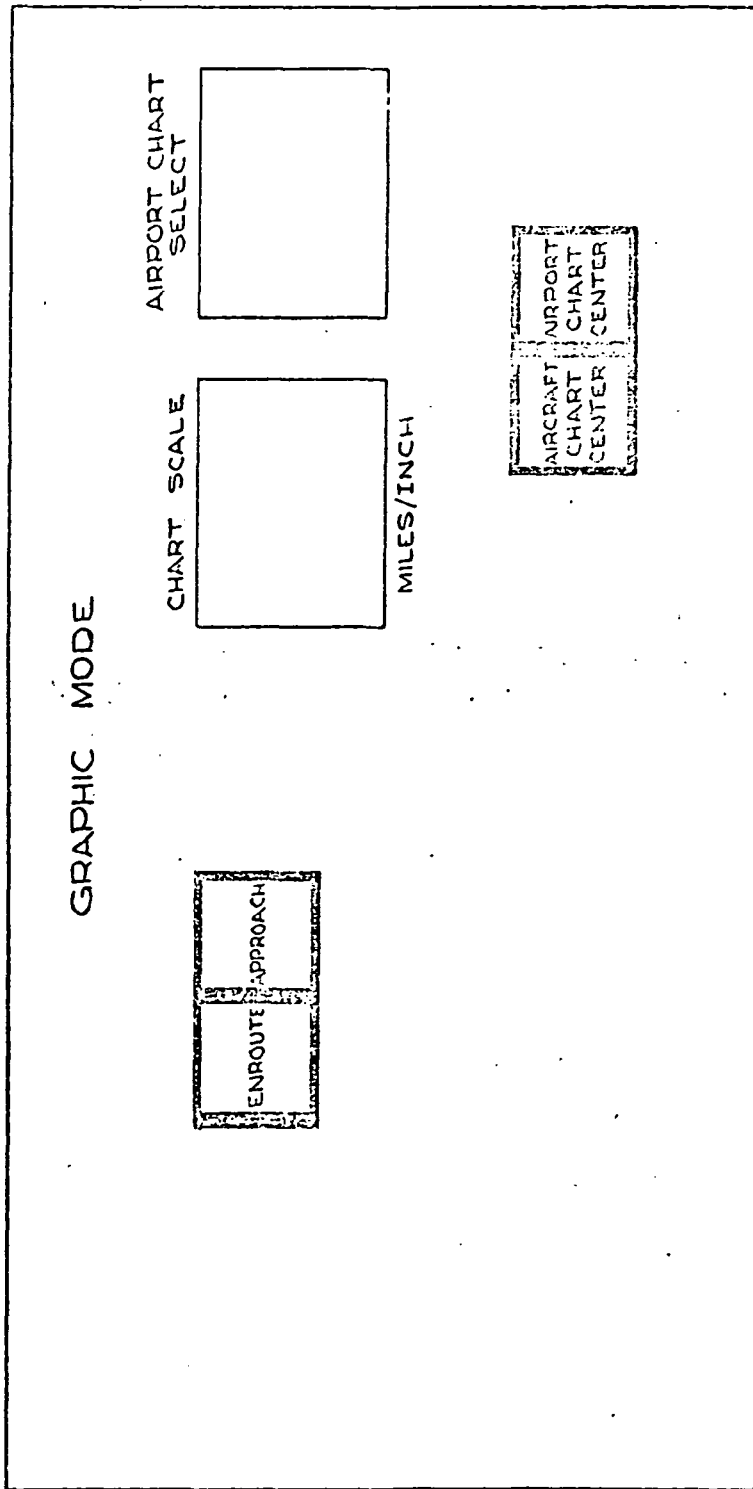
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GRAPHIC MODE PANEL

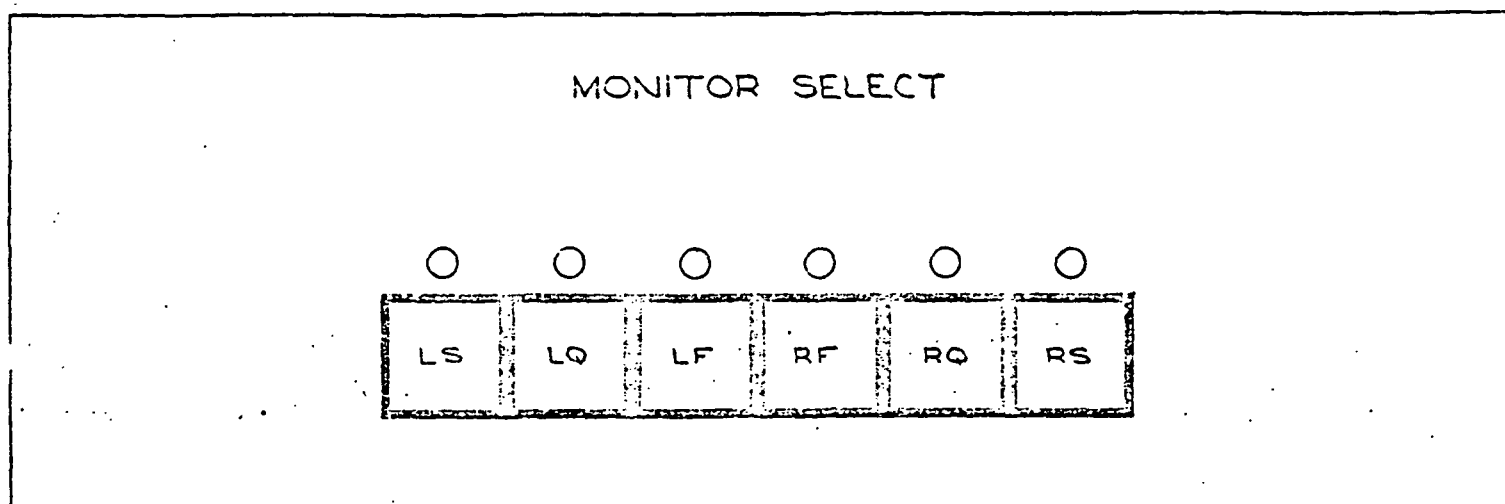
FIGURE 3.2.2-9

3.2.2.1.4.7 Monitor Select Panel

This control panel permits the instructor to monitor the visual scene as portrayed to the various crew positions (Reference Figure 3.2.2-10). Tell-tale lights illuminate when a visual scene is present in any of the crew position windows. A switch-light is provided for the instructor to select the visual scene he wishes to view on the visual monitor located on his console. The switch-lights are labeled as follows on the instructor's console:

- "LS" - Left side window
- "LQ" - Left quarter window
- "LF" - Left forward window
- "RF" - Right forward window
- "RQ" - Right quarter window
- "RS" - Right side window

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MONITOR SELECT PANEL

FIGURE 3.2.2-10

3.2.2.1.4.8 Speaker Panel

A speaker is provided at the IOS. The panel contains the speaker and the necessary controls for its operation (Reference Figure 3.2.2-11).

"VOLUME" - This control permits the sound intensity of the speaker to be varied.

"SPKR ON" - Activation of this dual action switch-light causes the signals normally provided through the headsets to be channel through the speaker.

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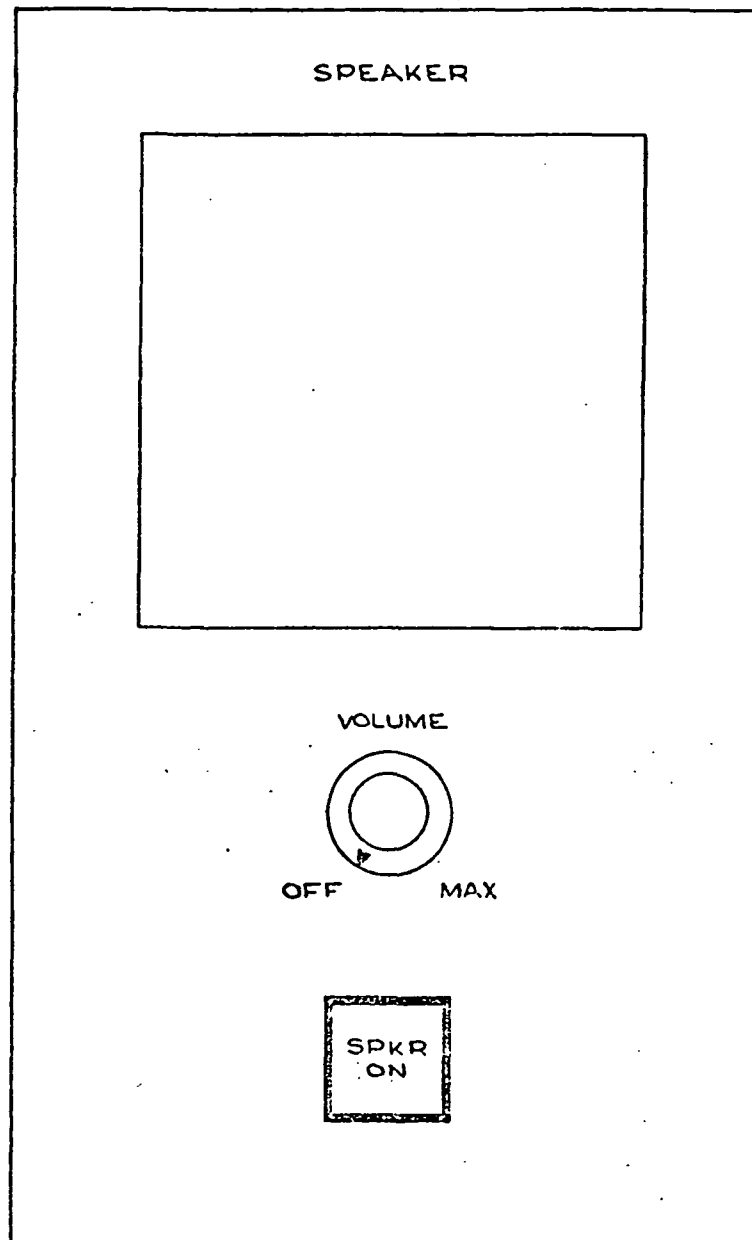
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SPEAKER PANEL

FIGURE 3.2.2-11

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3.2.2.2 In-Cockpit Instructor Station (Reference Figure 3.2.2-12)

Provisions will be made for an instructor station within the crew cabin of the motion-base crew station. This station will be occupied when the Mission and Payload Specialists' seats are not occupied. The instructor seat will be portable and installed prior to the mission for an on-board instructor. Fittings will be provided in the simulator to permit the installation and removal of the seat with a minimum effort and within a short time period. The seat will be located in the center of the forward crew cabin, just aft of the center console.

The instructor will be provided with a portable control panel for operating the simulator from this position. The following controls will be available to the instructor:

- a. "READY" light
- b. "OPERATE" switch-light
- c. "INT MCC" switch-light
- d. "RESET" switch-light
- e. Reset Thumbwheel selector
- f. "NORMAL" switch-light
- g. Spare
- h. "1/10 SPEED" switch-light
- i. "1/20 SPEED" switch-light
- j. "AUTO FREEZE ENABLE" light

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|                          |              |                  |                   |                              |
|--------------------------|--------------|------------------|-------------------|------------------------------|
| READY                    | OPERATE      | INT<br>MCC       | RESET             | RESET<br>THUMBWHEEL<br>KNOBS |
| NORMAL                   | FAST<br>TIME | 1<br>10<br>SPEED | 1<br>20<br>SPEED  |                              |
| AUTO<br>FREEZE<br>ENABLE | FREEZE       | MOTION<br>READY  | MOTION<br>OPERATE | EMER<br>STOP                 |
| CONTR<br>LOAD<br>OPERATE | TILT         | VIS<br>READY     | VIS<br>OPERATE    |                              |

IN COCKPIT  
INSTRUCTOR STATION

FIGURE 3.2.2-12

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- k. "FREEZE" switch-light
- l. "MOTION READY" light
- m. "MOTION OPERATE" switch-light
- n. "CONTR LOAD OPERATE" switch-light
- o. "TILT" switch-light
- p. "VIS READY" light
- q. "VIS OPERATE" switch-light
- r. "EMER STOP" switch-light

A description of the functional operation of these controls is contained in the corresponding paragraphs in Sect. 3.2.2.1.3.2, Operator Control Panel. The instructor would be provided a three-position thumb-wheel knob for selecting reset points used in conjunction with the "RESET" switch-light.

While operating from this position, the instructor will utilize the communication controls and headset jack at the Mission Specialist Station.

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### 3.2.2.3 Telemetry Operator Station

The Telemetry Operator Station serves to incorporate uplink commands and monitor of telemetry data into the training exercise. One Telemetry Operator Station will be provided to service both the fixed-base and motion-base simulators. Although telemetry and interface data may be inputted through any of the IOS's, this station will be utilized during training exercises when the work load at any of the IOS's is too great for the primary instructor to handle. During integrated crew training, exercises and mission rehearsals, the Telemetry Operator Station will be an integral part of the IOS complex.

The Telemetry Operator Station will consist of a CRT, a keyboard unit, and a communications control panel. The station is vertically stacked to conform with the design of the Commander-Operator IOS. The upper segment is canted downward 30 degrees from the vertical, the middle segment is vertical, and the lower section is inclined 45 degrees from the horizontal, and joins the horizontal writing surface. The upper tier contains a blank panel for future growth. The middle tier contains the Operator's CRT, and the lower tier provides space for the communications control panel. (Reference Figure 3.2.2-13.)

A writing surface, 16 inches deep provides adequate space for reference materials and for writing. The height of the writing shelf above the floor is 25½ inches (in confirmity with MIL-STD-1472 and MSFC-STD-267A) which allows the keyboard unit to be at a comfortable

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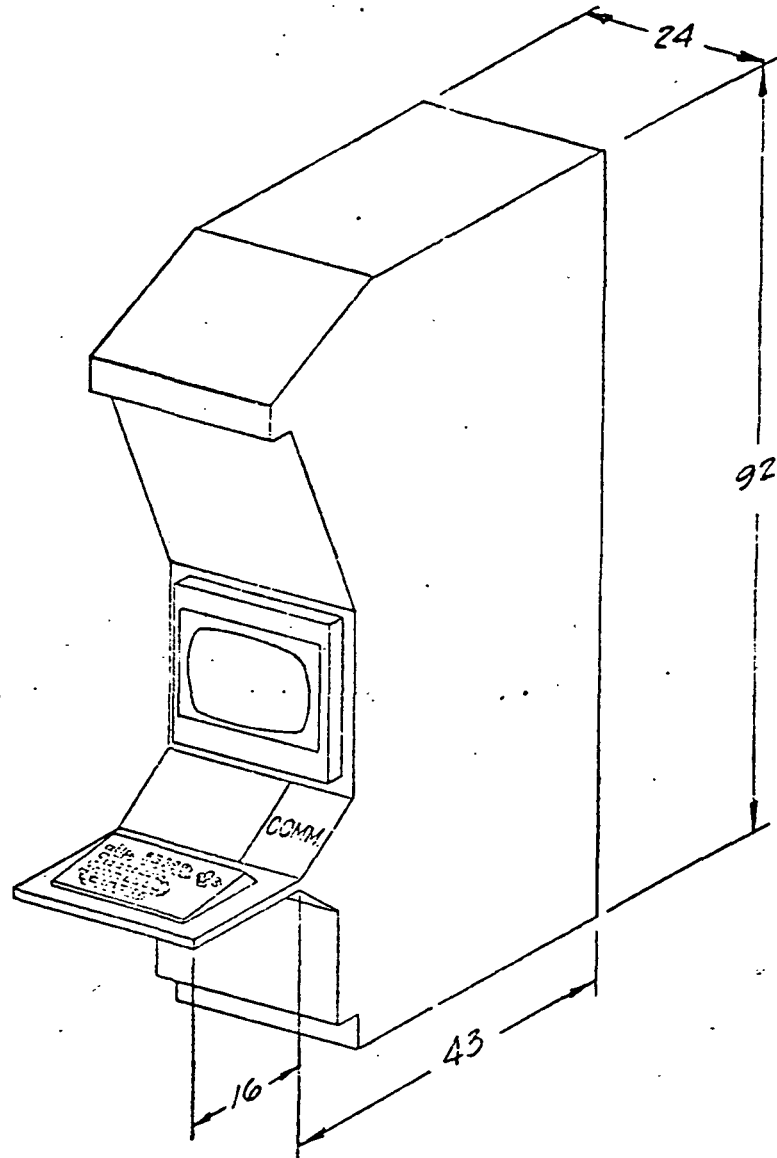
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TELEMETRY  
CONSOLE

I/O STATION  
SM5

FIGURE 3.2.2-13

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level, and yet provides ample knee room for the instructor.

3.2.2.3.1 CRT Display/Keyboard Unit

The CRT display/keyboard unit will provide the Telemetry Station operator with the necessary displays to monitor mission performance, and the required controls for entering all data associated with the telemetry and interface data function. The CRT will be capable of providing both alphanumeric and graphic data.

The display/keyboard unit will operate identically to those described previously in 3.2.2.1.1 and the same keyboard action will be used to select a display or modify a value stored in the computer. The top line of the CRT will always contain the following data:

- a. A one-or two-character display mnemonic identifying the display.
- b. Symbols indicating the ground station in contact with the vehicle; if none are in contact, LOS will be displayed.
- c. Mission elapsed time
- d. Simulated Greenwich mean time

CRT pages, identical to those available at the Commander-Pilot IOS, will be provided at the Telemetry Operator Station. The Telemetry operator will be able to call up a page display independent of the action at any other IOS.

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A description of these displays and the method by which the displays are called up is as outlined in Sections 3.2.2.1.1 through 3.2.2.1.2.14.

A separate CRT is not provided at the Telemetry Operator Station to display information associated with Event Time Monitoring functions. Therefore a page will be provided to display chronologically the most recent crew actions and will contain the same data as previously described in 3.2.2.1.2.1.

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### 3.2.2.3.2 Station Controls

The telemetry operator's station will contain no controls associated with the operation of the simulator. A Communications Control Panel will be provided for necessary communications with the trainee(s), other instructors, and personnel in support of the training exercise. The control panel will be located on the right side of lower tier in a position where it will not interfere with the operator's performance, yet conveniently located for its operation.

The communications controls on this panel are the same as those on the Commander-Pilot IOS for the MBCS and are discussed in Section 3.2.2.1.4.4.

Additional control panel functions will provide capability for IOS Lighting Intensity and Lamp Test.

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#### 3.2.2.4 Layout Mock-Up

A layout of the instructor's area along with the justification for that layout will be provided at the contractor's plant prior to specifying the firm requirements relative to the overall layout. Where major components are duplicated on the console (e.g., CRT displays) only one will be modeled in detail. The model will be as complete as necessary to permit evaluation of the general arrangement and installation of the following equipment.

- a. Location of the IOS's with respect to crew compartment stations.
- b. Instructor-operator flight compartment controls.
- c. Full scale replica of all instructor-operator stations.
- d. Instructor chairs.
- e. Lighting arrangement.
- f. Sample of panel painting and engraving.



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### 3.2.3 Ancillary Equipment

Ancillary equipment in the SMS includes the following:

- a) Simulator Power Hardware
- b) Aural Cue System
- c) External Interface Equipment
- d) Simulator Central Timing System
- e) Audio Communications System
- f) Simulator Maintenance Interphone

Some of this equipment, such as AC Power, Central Timing, and External Interface Equipment will be shared by the MBSC and the FBSC. Other equipment, such as the Aural Cue System, DC Power, and Audio Communications Equipment, will be provided for each crew station as required.

#### 3.2.3.1 Simulator Power Hardware

The SMS will be designed to operate from 277/480V, 120/208V 60HZ 3 phase power, and 115V 400HZ single phase power as indicated in Section 2.3.2.

Heavy motor loads will be connected to the 277/480 volt power source to minimize the effects of voltage surges to the rest of the simulator complex. Reference Figure 3.2.3-1.

The power turn-on sequencing system will be designed to prevent more than one motor from drawing starting current at a time. Maximum turn-on surge will result when the motion pump is turned-on while the Boost Pump and control loading pump are running. In this case, the load will be 118 Kva. Reference Figure 3.2.3-1.

Power sequencing control for the 227/480V power will be located in the motion system electronics cabinet (Reference Section 3.2.9).

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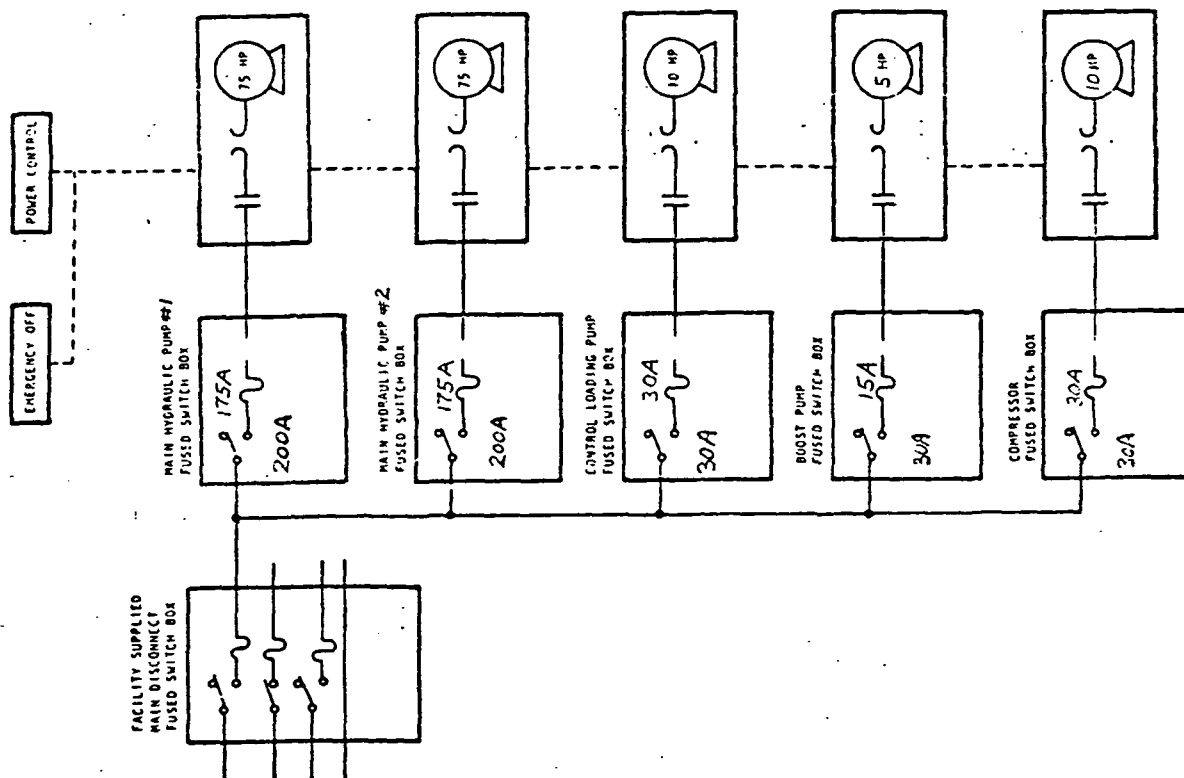
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NOTE: ONLY ONE PHASE SHOWN, TYPICAL

Figure 3.2.3-1 POWER CIRCUIT (277/480V, 60 HZ)

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A single double-bay cabinet will be used to control and distribute all 120/208VAC power to the simulator complex. The cabinet will contain sequencing controls, a phase warning indicator, an emergency stop button, a line voltage meter and selector, circuit breakers, and all the necessary electronics to control power sequencing.

Reference Figure 3.2.3-2.

Two double-bay cabinets will be used to distribute DC power; one for each simulator. The DC cabinets will be identical and will contain power supplies, voltmeters, ammeters, circuit breakers, and distribution busses.

All equipment and circuits will be adequately protected. Protection equipment will consist of circuit breakers, phase warning, and sequence lights. An overtemperature warning circuit, consisting of a warning bell, temperature sensors located in each cabinet, and warning lights to indicate which cabinet is overheated, will be provided. Readily accessible emergency-off switches will be located throughout the complex to disconnect all power to equipment.

#### 3.2.3.1.1 Power Sequence Control

A power sequence control system will be located in the AC power cabinet.. It will be designed to minimize turn-on surge current by sequencing the loads automatically at timed intervals. Feedback loops from the equipment will be used to initialize the succeeding power loads. If the feedback signal is not received, the turn-on sequence stops, requiring a recycle initiation or correction of the fault.

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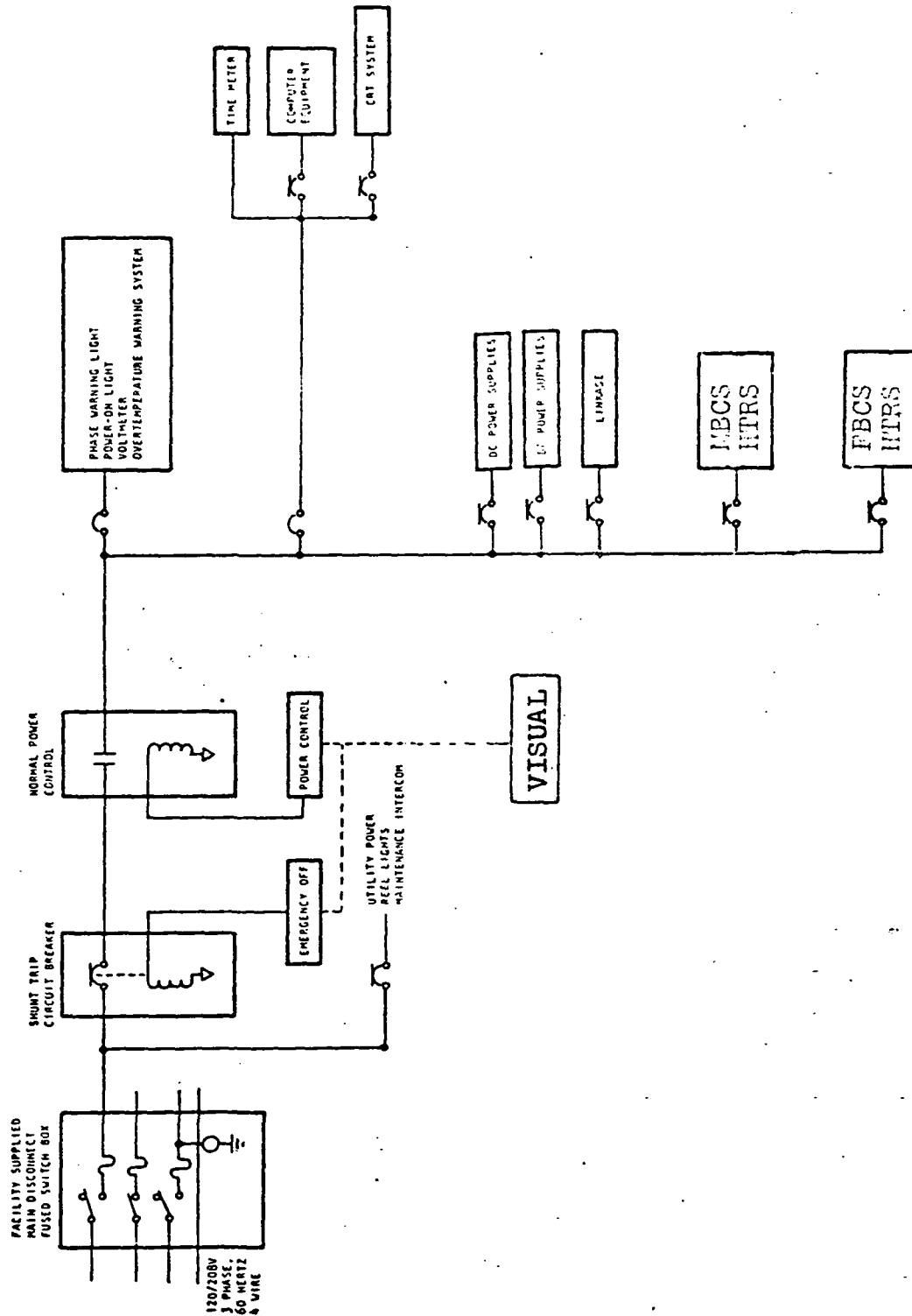
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MAIN POWER DISTRIBUTION (120/208V, 60 HZ)

Figure 3.2.3-2

Manual mode will enable maintenance personnel to trouble shoot the complex. In this mode loads may be turned-on in any sequence.

A system on/off switch will be provided to initialize the turn-on sequence. Remote switches at the Pilot/CDR Instructor's stations will also enable instructor initialization of the auto sequencing.

A Maintenance in Progress switch will prevent system power turn-on, thereby protecting maintenance personnel from potential shock hazards.

The sequence control turn-on order will be:

- 1) Hydraulic Power
- 2) Air Compressors
- 3) Cabinet Blowers
- 4) Linkage Ready/Fail
- 5) DC Load (MBCS)
- 6) DC Load (FBCS)
- 7) 400 Hz Load
- 8) Visual Power

### 3.2.3.1.2 Utility Power System

The utility electrical power circuit will be powered from the main power disconnect box and will be operable while the remainder of the simulator power is off. Trouble lights, reel-type recoil lights, instructor station lights, utility power outlets (W-C-596) and the maintenance intercommunication system are powered from this circuit. Utility lighting will be provided in the cockpit area, in the area under the motion platform, and in any other normally dark areas where maintenance may be required. Utility light bulbs will be guarded against accidental breakage, and each group of lights will be controlled by an ON-OFF switch.

### 3.2.3.1.3 400 Hz Power Control

NASA supplied 400 Hz power will be utilized in the SMS wherever necessary. The AC power cabinet will have control of this power by means of circuit breakers and contactors.

The 115V, single-phase, 400 hertz power will be distributed to loads through isolation transformers to help separate grounding systems. The 26V, 400-hertz power will be generated by stepdown transformers and protected by circuit breakers.

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#### 3.2.3.1.4 Power Cabinet Failures Indications (Figure 3.2.3-3)

A FAILURES INDICATIONS(FI) panel will be located at the AC power cabinet and will contain display lights indicating Overheat, Air Flow and Power Supply failures. A test switch will be incorporated to allow lamp test of the indicators.

##### 3.2.3.1.4.1 Overheat

Dual sensors will be placed in all cabinets and cockpit areas where potential overheating problems exist. One sensor will be set at 100°F and will cause both an aural and visual (FI panel) warning. The second sensor will be set at 110°F and will cause power shutdown in the event that this temperature is reached.

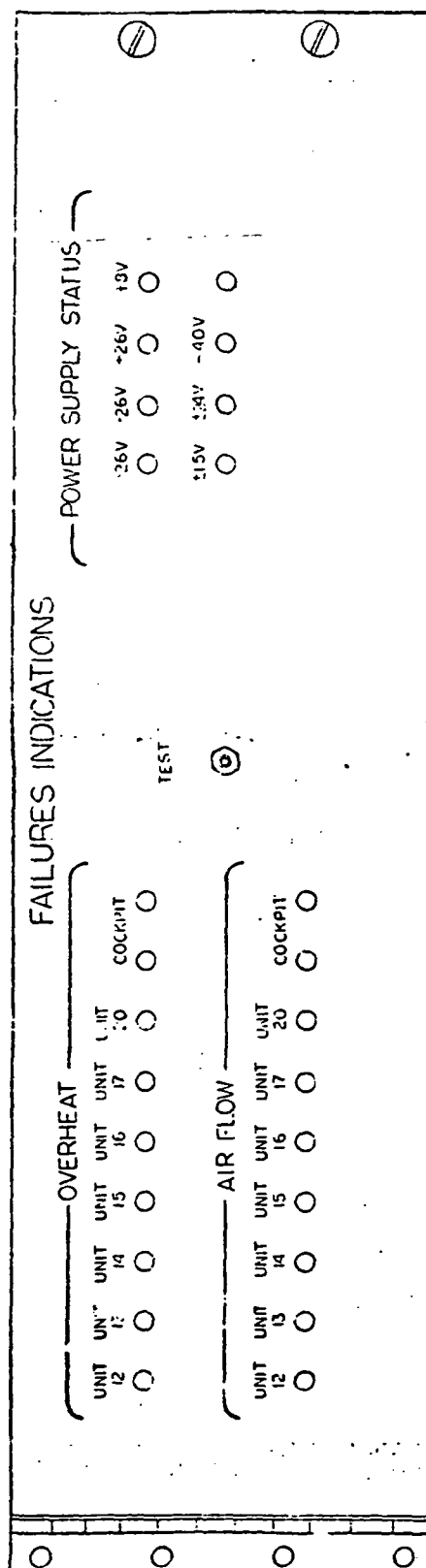
##### 3.2.3.1.4.2 Air Flow

Air flow sensors will be located in cabinets having fans or blowers. Indicator lights on the FI panel will illuminate whenever air flow is obstructed (e.g., clogged filter).

##### 3.2.3.1.4.3 Power Supply Status

An indicator light on the FI panel will illuminate whenever a specific DC power supply is not operating.





**Figure 3.2.3-3** FAILURES INDICATIONS PANEL (TYPICAL)

### 3.2.3.1.5 Electromagnetic Compatibility

EMI source minimization and containment techniques fall into the following categories:

- 1) Grounding
- 2) Bonding
- 3) Isolation of signals
- 4) Application of suppression devices
- 5) Shielding

The following paragraphs describe the techniques in each category that will be applied to the design of the SMS.

#### 3.2.3.1.5.1 Grounding

A single-point-reference grounding system will be established to control conducted interference on current return circuits, provide effective shielding, and protect personnel from electric shock. The ground subsystems, such as chassis ground and signal ground, will be completely isolated from one another, except at the central ground point, which will serve as the single-point ground for the system.

A signal ground plane of highly conductive aluminum will be established for DC voltage return distribution (signal ground). Material cross-section area will be evaluated on the basis of the DC current requirements, distance, and skin effects. The central ground plane and connecting radial sections will remain isolated from the copper tubing chassis ground except for a single-point connection at a central ground point.

The design and construction of the equipment will ensure that all external parts, surfaces, and shields are at ground potential at all times. Any external or interconnecting cable, where

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a ground is part of the circuit, will carry a ground wire in the cable terminated at both ends in the same manner as the other conductors. In no case, except with coaxial cables, will the shields be depended upon for a current-carrying ground connection. Plugs and convenience outlets for use with portable tools and equipment will have provisions for automatically grounding the frames or cases of tools and equipment when the plug is mated with the receptacle.

Initial requirements for establishing a grounding system will be as follows:

- 1) To provide a safety ground to personnel.
- 2) To provide a low-impedance return for induced currents on consoles, chassis, cable shields, etc.
- 3) To provide a signal-ground system that will not compromise the shielding effectiveness or safety consideration of chassis ground.
- 4) To provide the capability for the removal or modification of a system component without impairing the overall grounding system.
- 5) To provide a system that will be compatible with future modifications or extensions.

#### 3.2.3.1.5.1.1 Chassis Ground

Equipment cases, cabinets, racks, and electronic equipment enclosures will be referenced to the chassis grounding system, which will consist of copper tubing (95% International Annealed Copper Standard) with a minimum inside diameter of 0.75 inches. Mating surfaces will be (preferably) welded by exothermic process around the entire periphery of the mating surfaces.

Bolted sections, such as that depicted in Figure 3.2.3-4 will have consistent contact pressure over an extended period of time, possess high resistance to corrosion effects, and exhibit a resistance no greater than 0.5 millionms. Bonding connections will be made as depicted in Figures 3.2.3-5 and 3.2.3-6 using methods approved by NASA in NHB 5320.3.

The chassis ground will be run under the computer floor, as shown in Figure 3.2.3-6 directly beneath the electronic cabinets to facilitate the bonding of the chassis ground of the cabinet by means of a bond strap of minimal length. All exposed conductive parts, shields, control shafts, switch handles, bushings, etc., will be grounded to the chassis ground for safety considerations to operating personnel. Internal metal parts and modules, filter cases, transformer shields, etc., will also be grounded to chassis ground.

#### 3.2.3.1.5.1.2 Signal Ground

The signal ground plane will consist of a large aluminum bus bar at least 8 inches in width which will be placed beneath the floor. The bus bar will be close enough to the surface to facilitate bonding to the signal ground busses in the cabinets using bonding straps with good width-to-length ratios.

The width of the bus will be chosen to maintain a signal ground of low impedance to fast-rise-time signals. The signal ground will be isolated from all other ground except at the central ground point.

In the event that the chassis ground and signal grounds are connected together in a piece of commercial equipment, a significant

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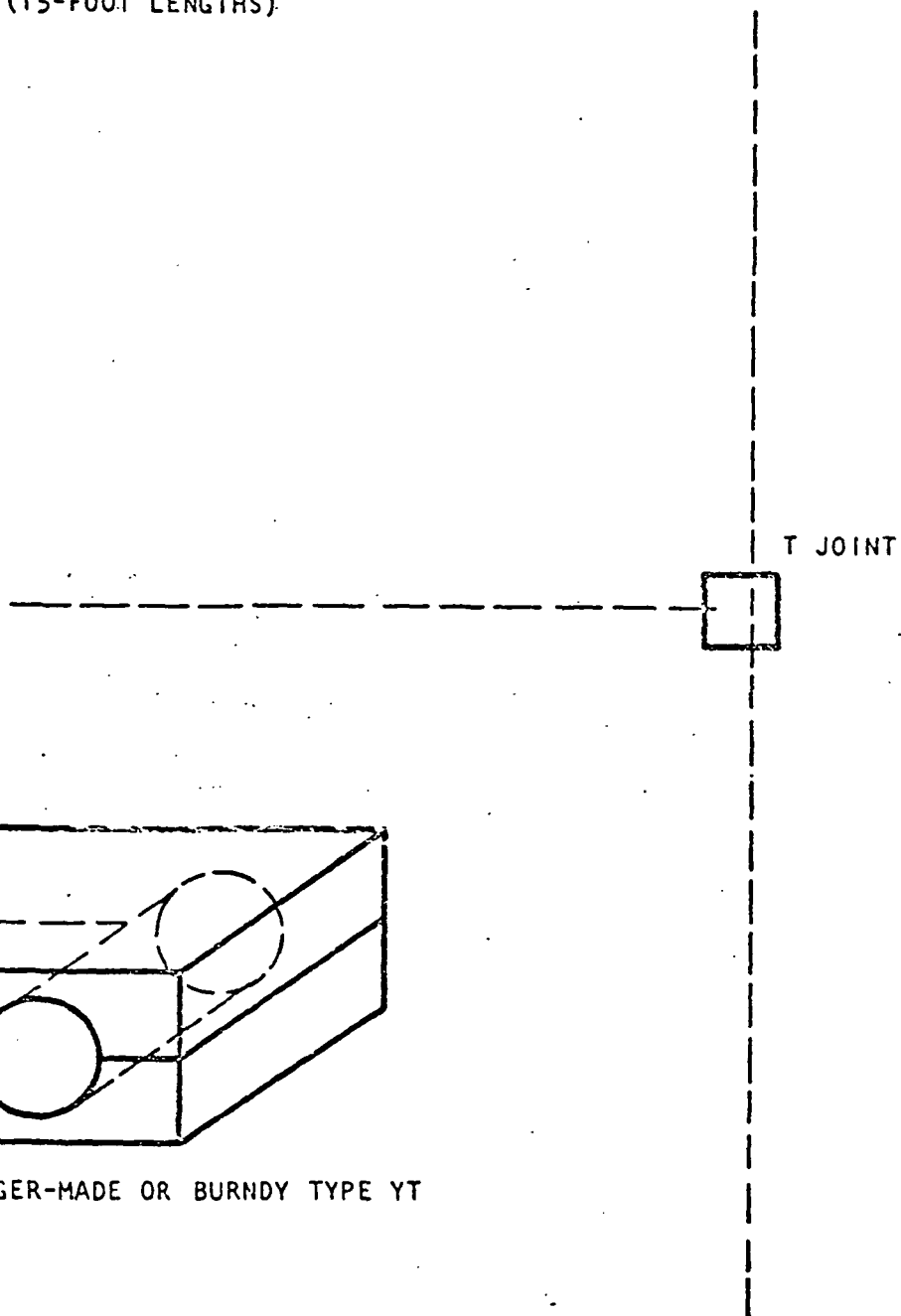
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Figure 3.2.3-4 CHASSIS GROUND SYSTEM CONSTRUCTION

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METHOD OF CONNECTING BOND STRAPS  
TO CHASSIS GROUND BUS  
(FROM AFSC DESIGN HANDBOOK DH 1-4)

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SUB-NOTE 1(1) CLAMP  
CONNECTION - JUMPER  
TO TUBE

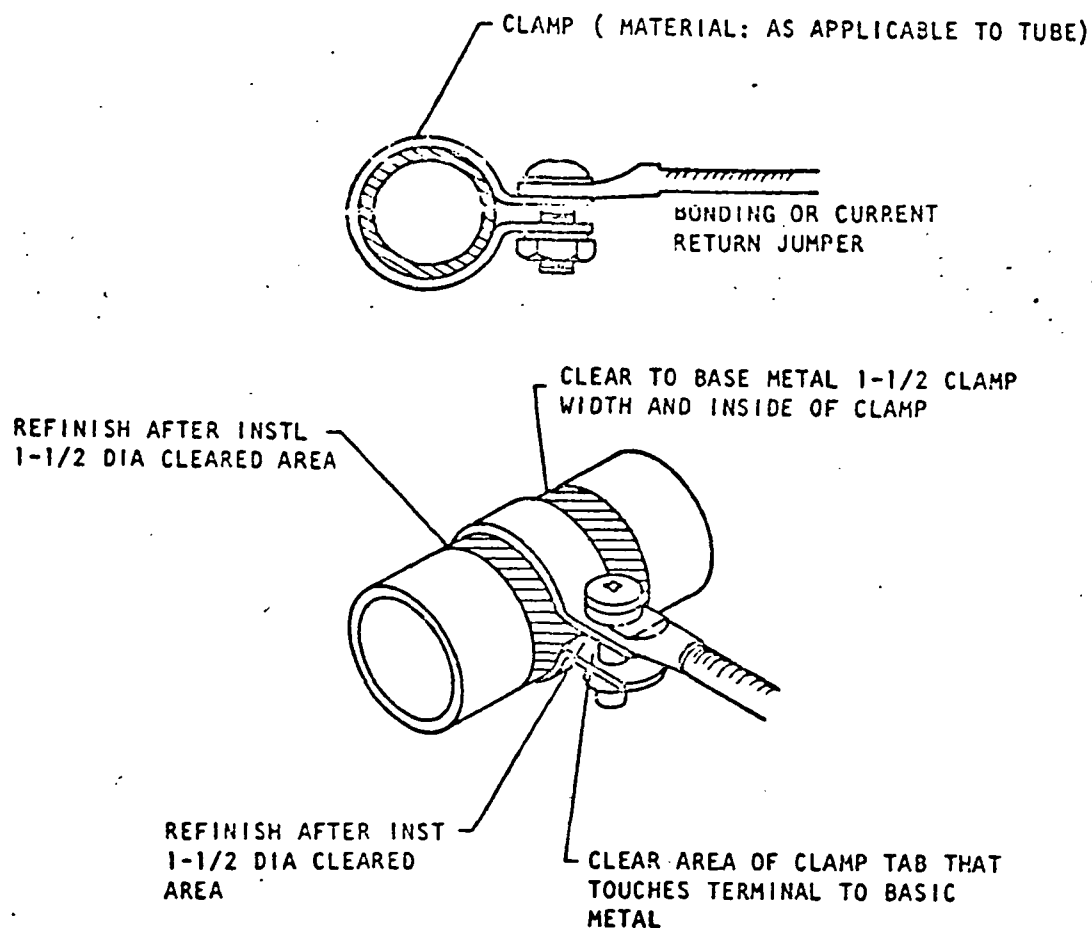


Figure 3.2.3-5

METHOD OF CONNECTING BOND STRAPS TO CHASSIS GROUND BUS

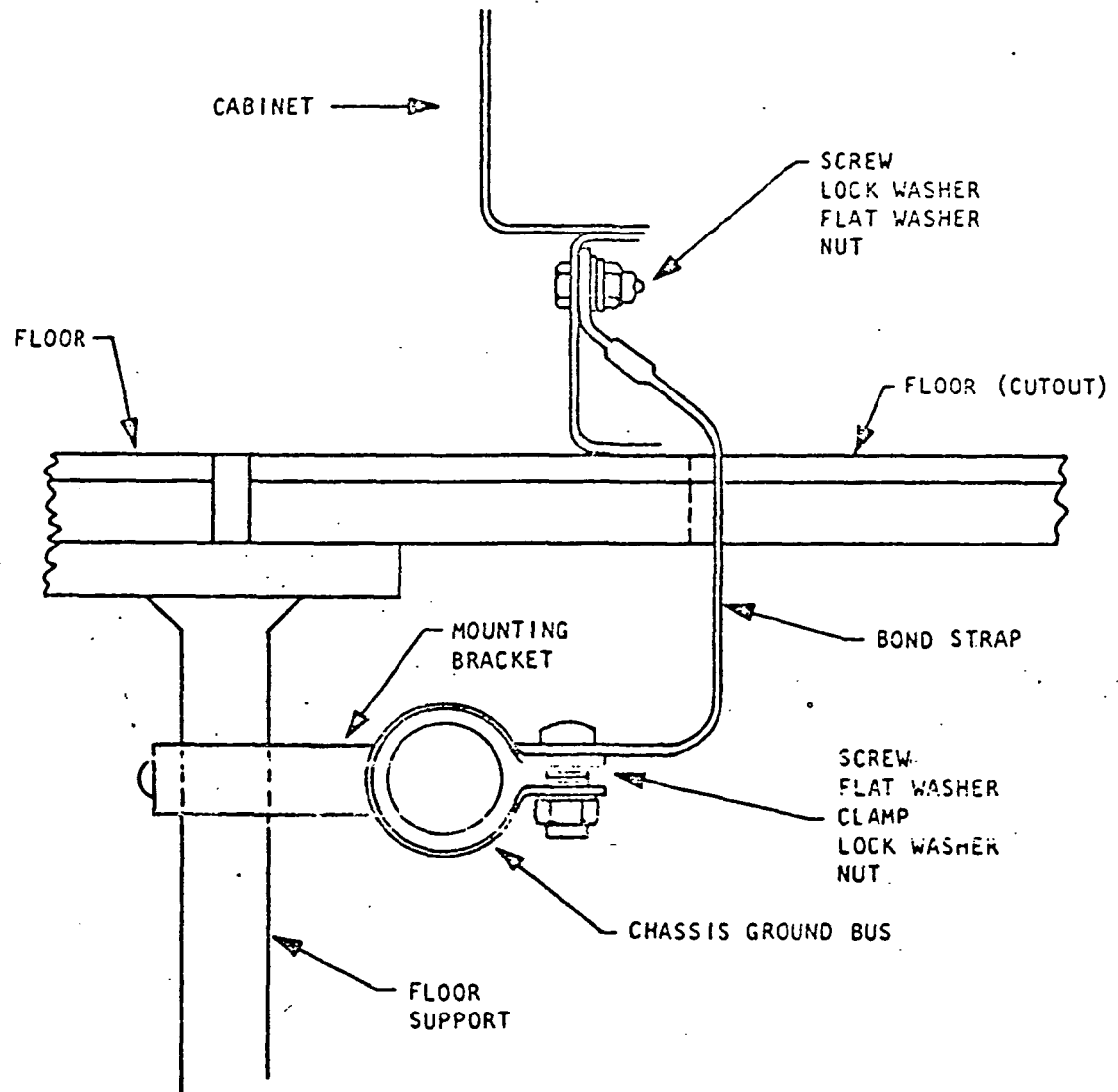


Figure 3.2.3-6

METHOD OF CONNECTION OF CABINET TO CHASSIS GROUND

effort will be applied to isolate this unit from the rest of the equipment and reference it to the low-impedance signal ground bus.

#### 3.2.3.1.5.1.3 Primary Power Neutral

Primary power sources and circuits will not be directly grounded to chassis or signal ground within the simulator. Each AC neutral will be routed with its associated power leads and maintained above earth potential in all equipment stations.

The AC voltage feeding all internally grounded instruments or panel loads will be supplied from isolation transformers whose secondary leads will be run to each load. The secondary of the isolation transformer will be grounded at the load end only in a manner not dependent on the mounting of the instrument case to the panel. This grounding will be achieved by a separate wire bonded directly to the panel with a screw and nut. The instrument will not be dependent on its mounting to provide a reference ground.

#### 3.2.3.1.5.1.4 Interface Grounds

Interfaces between the flight simulator equipment will be provided with chassis ground interconnections as follows:

- 1) Each cable carrying primary or secondary AC or DC power will be provided with a chassis ground wire.
- 2) Power and signal returns will not be used as chassis ground wires.
- 3) A minimum of one interconnecting chassis ground will be required for each interface. If there is no power cable interconnection, the ground will be routed in the cable carrying the most



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sensitive circuits. Interfaces for commercial metering or signal-generating circuits will be exempt from this interface chassis ground requirement.

- 4) Interfaces of coaxial cables will not require additional ground interconnections. Coaxial cables will not be used for the interconnecting grounds for other cables.

### 3.2.3.1.6 Electrical Bonding

The electrical bonding procedures of MIL-STD-1310 and MIL-B-5087 will be utilized as design guides. Bonding considerations fall generally into the following categories:

- 1) Bonding of the enclosure to an equipment ground reference.
- 2) Bonding of separable or movable parts or openings.
- 3) Bonding of ground cables to the associated ground.
- 4) Bonding of the major subassembly to chassis ground.

The bonds between the equipment and the central ground point will be designed to carry the maximum short-circuit fault current load of the equipment.

All electrical and electronic units or components which produce electromagnetic energy will be installed to provide a continuous low-impedance path from the equipment enclosure to the central ground point. Bonding will be designed to provide for a direct current impedance of less than 2.5 milliohms from the enclosure to the central ground point. The bond from the equipment enclosure to the mounting plate furnished with the equipment will also comply with these requirements, except that suitable jumpers may be used across any necessary vibration isolations. The ratio of length to

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width of the jumper braid cables will be 5/1 or less.

Protective finishes will be omitted at those points where their presence would prevent proper electrical bonding, such as required for shielded or electrical connection. Provision will be made to assure permanence of the electrical contact between the surfaces of all parts in contact over long periods of time.

Bonding installations will be considered as being permanent and inherently bonded when utilizing metal-to-metal joints by welding, brazing, sweating, or swagging. Insulating finishes will not be removed if the resistance requirement is met without such removal. Examples of semipermanent installations are:

- 1) Bare metal-to-metal joints of machine surfaces held together by thread-locking devices.
- 2) Riveted joints with a minimum of three rivets.
- 3) Tie rods.
- 4) Structural wires under tension.
- 5) Pinned fittings driven tight.
- 6) Normally permanent and immovable clamp fittings which have been removed from the contact area.

Bonding connections will be so installed that vibration, expansion, contraction, or relative movement incident to normal service use will not break or loosen the connection to such an extent that the resistance will vary during the movement. Bonding connections will be located in protected areas, insofar as practicable, and whenever possible near a hand hold, inspection door, or other accessible locations to permit rapid inspection or replacement. The following conditions will also apply:

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- 1) Parts will be bonded directly to the basic structure rather than through bonded parts. Shielded wire grounds will be carried through the pins of a connector or attached directly to the grounding structure. Bonding through the connector shells will be permitted, provided the resistance through the shell is not greater than 2.5 milliohms.
- 2) Bonding jumpers will be installed so that movable components are not impeded in their operation by the jumper.
- 3) Bonding connections will not be compression-fastened through nonmetallic materials.
- 4) Bonds on plumbing lines will not be dependent on mounting clamps because of differential thermal expansion.
- 5) Cushion clamps will not be used for bonding purposes.
- 6) All equipment cabinets will be furnished with mounting holes for studs for a bonding strap ground connector.
- 7) The use of conductive epoxy resins will be permitted, provided they conform to the performance requirements of the SMS contract. When bonding by jumpers would cause fouling or mechanical malfunction, other suitable means will be employed.
- 8) Bonding of cylindrical or tubular conducting members not inherently bonded will be accompanied by a clamp with a jumper. Bonding clamps, when required on flexible metallic conduit or hose, will be so installed as not to crimp or damage the conduit or hose.

- 9) When joining dissimilar metals cannot be avoided, the jumpers and other elements of the bonding connection will be selected to minimize the possibility of corrosion. If corrosion does occur, only replaceable hardware items, such as jumpers, bolts, nuts, washers, or separators, will be affected rather than the structure. Self-tapping screws and zinc-plated bolts, nuts, and screws will not be used. Washers will not be surface-treated or coated in any manner that will impair electrical conductivity. Unprotected, non stainless steel will not be used as a washer. Anodized or zinc-plated washers will not be used.

Intermittent electrical contact between conducting surfaces which may become a part of a ground plane or a current path will be prevented either by bonding or by insulation if bonding is not necessary to conform to this standard.

### 3.2.3.1.7 Methods of Eliminating Spurious Responses and Connections

#### 3.2.3.1.7.1 Isolation of Signals

Wires and cables will be classified as delineated below:

Class I - Class I wires are interference-producing wires which interconnect equipment, or circuits that are insensitive to interference. Examples of Class I are alternating current (AC) power wiring, relay and stepping motor wiring, actuating power wiring, and flashing incandescent and fluorescent wiring.

Class II - Class II wires are those that in themselves are not interference-producing, but are connected to interference-sensitive equipment or circuits. Examples of Class II are audio and video outputs, metering and bridge circuits, direct current (DC) and AC reference voltages, and receiver inputs.

Class III - Class III wiring includes those circuits and equipment interconnections that are both interference-producing and sensitive to interference. Examples of Class III are pulse inputs and outputs of digital equipment.

Class I wires that are cabled together will be separated from Class II and Class III cables by a minimum of 6 inches or will be run at right angles to them. Class II wires cabled together will be separated from Class III wires by a minimum of 3 inches. Routing of cables will be determined mainly by the interference producing or susceptibility characteristic of each. Cables and wiring inside cabinets will follow the minimum separation distances given above wherever possible.

#### 3.2.3.1.7.2 Application of Suppression Devices

All relays and other inductive devices, such as solenoid valves, will be protected by diode, capacitor, or resistor suppressive devices.

Diode/capacitor decoupling will be used on each printed circuit card, as well as being distributed throughout the logic gates. Particular attention will be paid to the impedance and resonant frequency characteristics of bypass components to ensure proper bypassing for required frequency components.

All high-frequency circuits will be decoupled as close as possible to the generating circuits.

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### 3.2.3.1.8 Shielding

Shields of low-level signal leads and of leads associated with steep-wavefront signals will be grounded at one point only and will be routed through pins of all connectors encountered. Digital input-output cabling will consist of wires surrounded by an overall shield which is terminated via a shielded twisted pair or twisted triplet cable. Other shielding configurations may be utilized, depending on the frequency involved, length of transmission, and amplitude of the signal level. Shields of all leads external to the equipment will be covered with an insulating material to prevent unintentional contact with conductive surfaces, except in the case of rigid conduit.

Each shield of low-level circuits will be grounded at one point only, preferably at the source end. The length of wire tying the shield to ground will be as short as possible, and never longer than 6 inches (see Figures 3.2.3-7, 3.2.3-8 and 3.2.3-9). Each shield of high-energy circuits used to contain low-frequency energy (less than 1 megahertz) will be grounded at one point only to chassis ground. The wire used to connect the shield to chassis ground will be as short as possible.

Each shield of high-energy circuits used to contain high-frequency energy (greater than 1 megahertz) will be grounded at each end as shown in Figure 3.2.3-9.

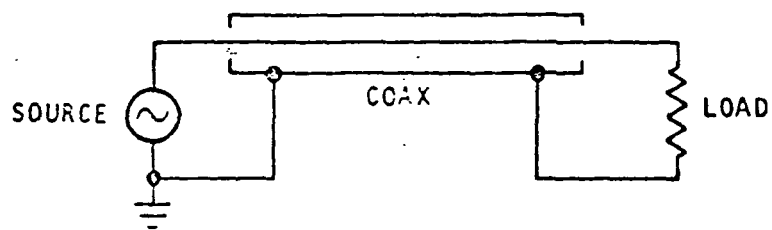


Figure 3.2.3-7 SHIELD GROUNDING OF LOW-FREQUENCY CABLES

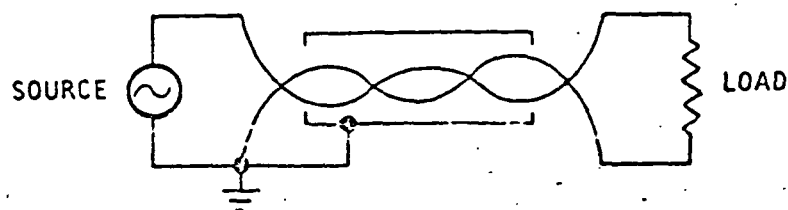


Figure 3.2.3-8 SHIELD GROUNDING OF TWISTED-WIRE CABLE

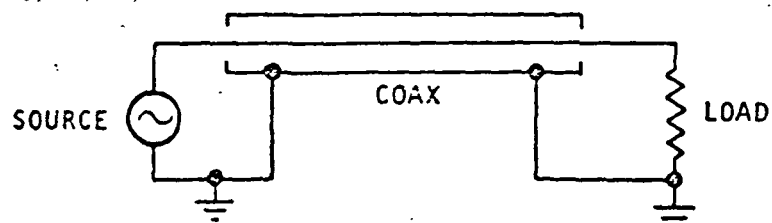


Figure 3.2.3-9 SHIELD GROUNDING OF HIGH-FREQUENCY COAXIAL CABLE

Coax will be grounded as shown in Figure 3.2.3-7 except when it is carrying high energy (greater than 5 watts) at high frequency (greater than 1 megahertz), in which event it will be grounded as shown in Figure 3.2.3-9.

All shields of audio circuits will be grounded at one end only. Wherever possible, audio shields will grounded as shown in Figure 3.2.3-8. The actual ground point will be at the source end. All audio leads greater than 6 inches in length will be twisted and shielded. The wires tying shields to ground will be as short as possible, and no longer than 6 inches. Audio shields will be referenced to the chassis ground.

Low-level video shields will be grounded as shown in Figure 3.2.3-8. Different shields may be referenced to different video ground planes as required, but each shield will be referenced to ground at one point only.



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### 3.2.3.1.9 Cable Routing

The raised computer flooring will provide space for routing cables between the equipments of the SMS, such as the Digital Computation System, the DCE, Ancillary Cabinets, the Instructor Operator Stations and, when possible, to the Crew Stations.

Cabling will be divided into three electrically and physically separated groups; power, signal, and audio.

All cabling below the computer floor will enter SMS equipment cabinets through the bottom. Cabling to the Motion Base Crew Station will be routed to the centroid location of the crew station/motion system and to the motion electronics cabinets. The cables will be of sufficient length to avoid stress during all excursions of the motion system. Care will be taken to minimize cable movement, and adequate cable protection will be provided.

### 3.2.3.2 Aural Cue System

#### 3.2.3.2.1 General Requirements

Aural cue simulation is becoming increasingly important in the light of the added complexities of modern aircraft. Human-factors studies have shown that aural cues have a significant effect on the training performance of students attempting to become proficient in highly complex skills. This effect manifests itself in two ways:

1) The training environment is greatly enhanced because auditory stimuli are second in importance only to visual stimuli in the flight environment; kinesthetic stimuli rank third.

2) Learning curves and concentration abilities are subject to degradation within the confines of high ambient noise environments. Within the cockpit of a modern aircraft it is not uncommon for the ambient noise level to reach sustained values of 90 to 110 db. Within this environment, even the advanced student's learning curve could be degraded some 15%. There is some evidence to support the contention that reaction times are elongated, the latency of response being a function of the nature of the decision that is required to result in the corrective action.

Aural cue simulation requirements for the MBCS include the generation of a large repertoire of sounds as needed to represent the Shuttle Orbiter Vehicle acoustic environment during normal and abnormal operation.

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The system conceived for the MCCS will consist of five simultaneously occurring subsets of aural events, whose combination forms a single, highly complex presentation. Within each subset there are specific, discernible events characteristic of particular mechanisms whose sounds emerge from their different directions.

These aural events simulations will be implemented by a combination of mathematical models and associated computer programs and electronic equipment as described below.

#### 3.2.3.2.2 Aural Effects Models

1) ABPS Engines (5) - This model will include LP compressor, HP compressor, HP turbine, LP turbine, and jet blast sounds for each Pratt and Whitney F401-FW-400 engine, inclusive of engine deployment, starter sounds, ignition, reverse thrust conditions, primary compressor stalls, and in-flight flameouts, all with altitude and airspeed corrections.

#### 2) Rocket Engines (SRM, MPS, RCS, OMS)

By virtue of the sequence of events in the mission time line, the ABPS engine aural cue simulation modules can also be used for these engines.

a) SRM (2) - This model will include thrust sound and vibration, start-up, shutdown, and thrust termination noises.

b) MPS (3) - This model will include rocket engine blast with throttle controllable sounds, start and post firing metal expansion/contraction noises, and system purging.

c) RCS (3) - This model will include jet "thump" and blast.

d) OMS (2) - This model will include rocket engine blast with throttle controllable sounds, start, etc.

3) Aerodynamics

This model will include aerodynamic air flow to structure noise as a function of aircraft attitude, altitude, and airspeed corrections. Transonic and supersonic performance effects will be provided. Popping and cracking sounds associated with reentry will also be provided.

4) Auxiliary

This model will include taxi pavement noise, landing gear, wheel touchdowns, air-conditioning duct blasts, hydraulic motor hum, pyrotechnic noises, electrical system, and fuel cell venting sounds.

5) Clunk Noise Generator

This model will include the various "clunks", "bangs" and "thumps" of the spacecraft such as; drag chute and speedbrake deployment, manipulator arm mating and stowage, cargo latching and unlatching, pyrotechnic separation, and docking.

All aural cues will be presented within the cockpit enclosure as quasi-elevated (nonplanar), bilateral, quadriphonics with "sounds in motion" where required as a realistic adjunct to the training environment.

3.2.3.2.3 Aural Cue Electronic Equipment

Electronic equipment for the aural cue simulation will consist of a device called the Poly-Voice Aircraft Sound Synthesizer\*\*

plus audio amplifiers and sound transducers placed at selected locations in the crew station. (Figure 3.2.3-10)

\*\* Patent applied for.

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LEGEND



= SPEAKER



= AUDIO TRANSDUCER

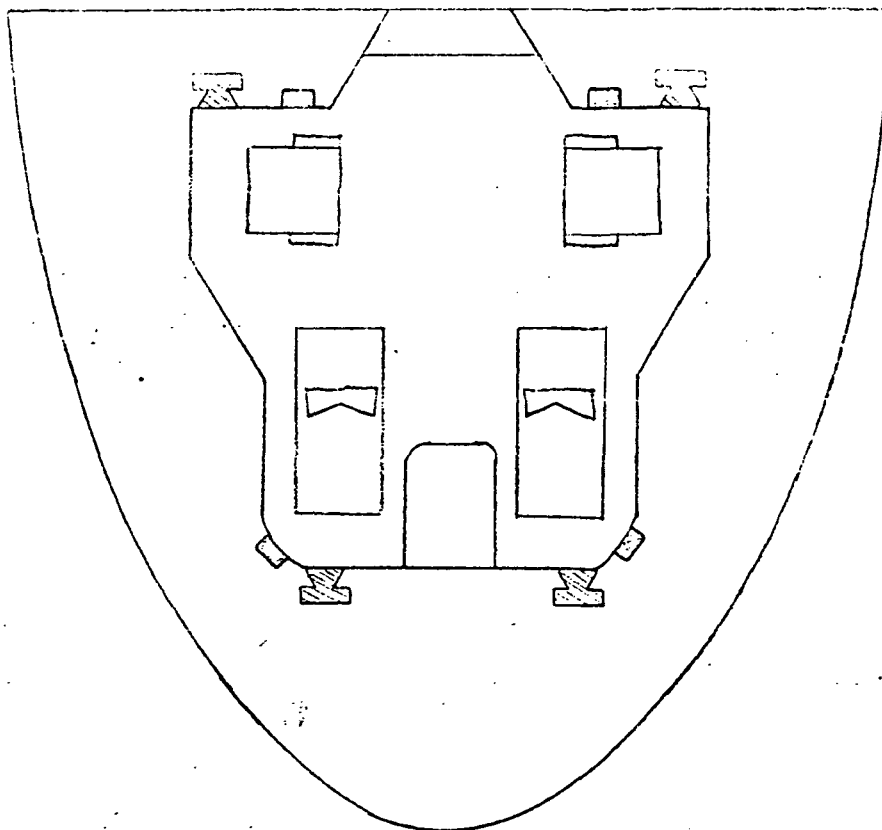


Figure 3.2.3-10 Aural Cue Speaker Locations

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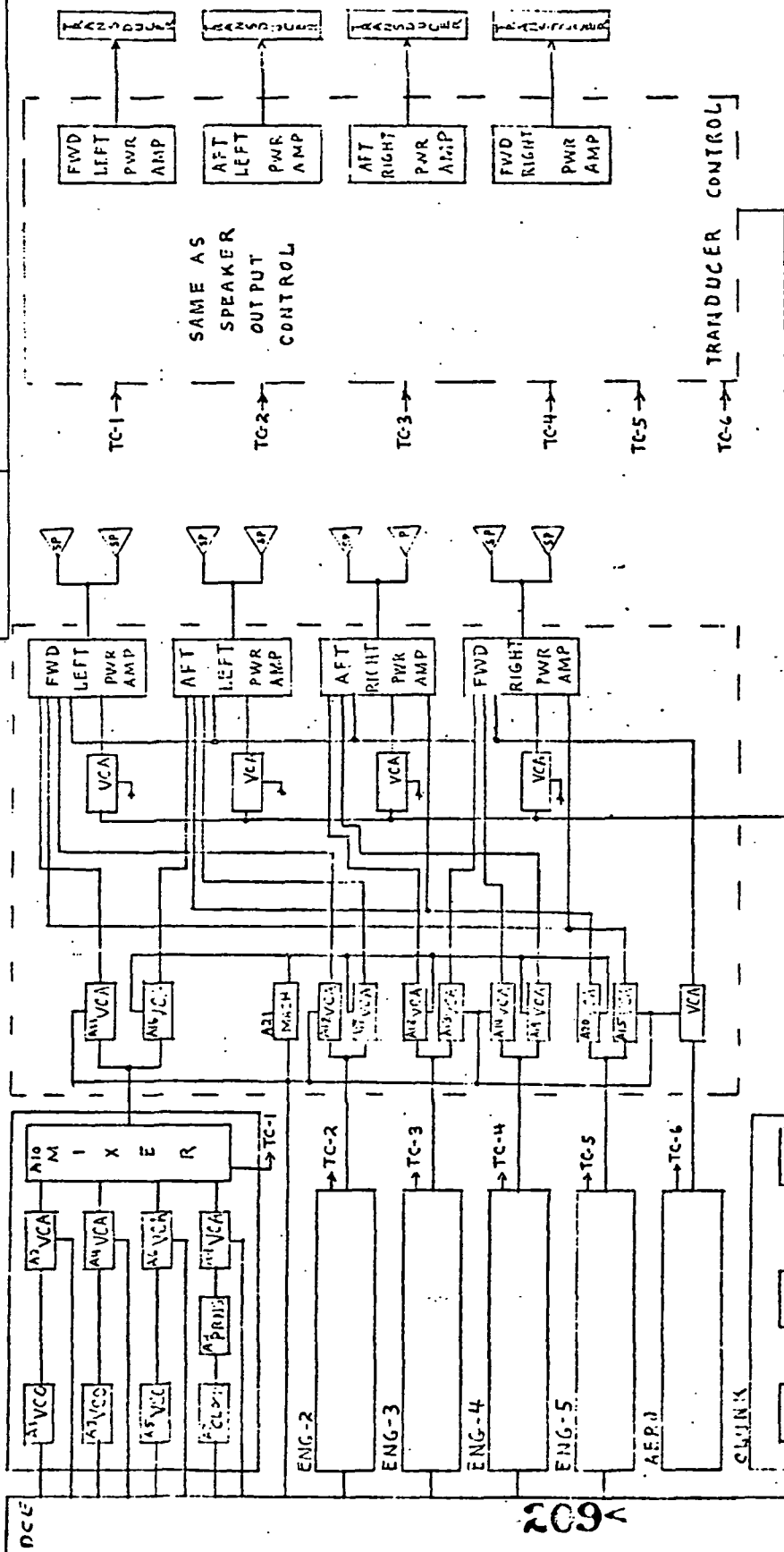
The Poly-Voice Synthesizer itself will consist of an array of electronic function generators (VCC's) and controllers (VCA's) designed according to the required configuration of parametric elements, as shown in Figure 3.2.3-11. The following paragraphs describe the system in detail, with reference to Figure 3.2.3-11.

### 3.2.3.2.3.1 Engine Sounds

Sounds of the ABPS turbofan jet engine Number 1 will be implemented by means of system parameters A1 through A10. Primary acoustic constraints will be systematically related to the main moving parts of the F401 engine. A1 will generate the HP turbine blade passage frequency of proper timbre (harmonic content) under the control of the N-1 function. A2 will suitably control the amplitude of this blade passage whine via a controlling function. Similar functions will control parameters A3, A4, A5, and A6 to simulate the low- and high-pressure compressor blade frequencies. Jet blast will be effectively simulated by means of a clocked pseudo-random noise generator that provides a unique method of accurately controlling the spectral makeup of the noise relative to engine performance parameters. Module A9 will control the jet blast amplitude relative to the blade passage frequencies, while A10 will sum the components and provide a composite acoustic facsimile which may later be modified during "transonic/supersonic" performance.

SPEAKER OUTPUT CONTROL

ENG-1



AURAL CUE  
FIGURE 3.2.3-11  
POLYVOICE SYNTHESIZER FUNCTIONAL  
DIAGRAM

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Engines 2, 3, 4, 5 will be independently simulated in a similar fashion. The additional engine signals will also be subjected to modification during transonic/supersonic flight, and the mutual acoustic constraints of the multi-engined configuration will be accounted for.

#### 3.2.3.2.3.2 Mach Shift

Rocket engine acoustics during transonic and supersonic flight necessitate special concern because the engine noise is the only primary acoustic frame of reference. This noise will therefore be subject to the transmission degradation that occurs whenever the speed of the acoustic source (or fluid transmission mechanism) relative to the observer exceeds the propagation rate of sound. Since the engine noise will be presented to the observer (trainee) via two separate paths - an airborne link and a structural link - "stereophonic source localization" will occur. At subsonic speeds, when both transmission links remain unaltered, the engines will appear to be just forward of their real position, dependent on the delicate amplitude balance of the multipath presentations. During transonic and supersonic flight, the airborne transmission path will be either partially or totally reduced. The result of such a multipath balance disturbance will be an apparent shift forward in localization just as occurs in the actual spacecraft.

Since the aircraft structure more easily transmits the lower-frequency noise, the acoustic makeup of the engine noise will be



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changed. Hardware parameters A11 thru A15 will provide engine signals representative of structural transmission, while A16 thru A20 will provide a close facsimile of airborne contributions. The function "MBK" and controller A21 will provide suitable control over the supersonic modifiers. Proper directional cues will result from the quadriphonic audio power system. (see Figure 3.2.3-10 for speaker locations)

#### 3.2.3.2.3.3 Aerodynamic Noise

Slipstream air and structural noise will be provided by a separate source A97 that is capable of well-defined control of its spectral content as a result of controllers, which reflect acoustic parameters dependent on aircraft (Mach) and logarithmic altitude.

#### 3.2.3.2.3.4 Auxiliary Sounds

A number of auxiliary sounds will be provided in multiplexed fashion by hardware elements, owing to their time sequenced rather than simultaneous nature. The individual cues, such as air conditioning, taxi, pavement or touchdown, and associated gear motions, will be created by commanding the proper acoustic parameters, and defining a particular direction of initialization with direction-select gates.

#### 3.2.3.2.3.5 Clunk Noise

The various "bangs", "thumps", and "clunk" noises associated with speedbrake deployment, docking, pyrotechnic separation drag chute, and manipulator arm mating, will be created by hardware elements.

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Directionality will be controlled by direction-select gates.

#### 3.2.3.2.3.6 System Packaging

The Poly-Voice sound system is packaged in three 19-inch rack-mounted modules (see Figure 3.2.3-12). The upper module is a rack mount tray 7 inches high which mechanically supports and electrically isolates a four-channel power amplifier. The power amplifier receives its input signals from the lower module and delivers output power to sound transducers mounted at four locations in the cockpit of the flight simulator.

The center module is a housing for the three DC power supplies occupying another 7 inches of rack height. This module also contains three pilot lights, five phone jacks, three fuses, and power switch. The pilot lights are connected individually to the outputs of the three power supplies. The phone jacks are connected to each of the four output channels and one composite channel formed by summing the other four. A separate fuse for each side of the line and a spare fuse are mounted on this panel.

The lower module is a card cage 10½ inches high containing functional (four types) 4½ x 12-inch circuit cards and an extender card for use in calibration or repair. The functional circuit cards hold the circuitry which generates, mixes, and controls the waveforms which comprise the composite output signals. Built-in test modes facilitate troubleshooting and maintenance of the system.

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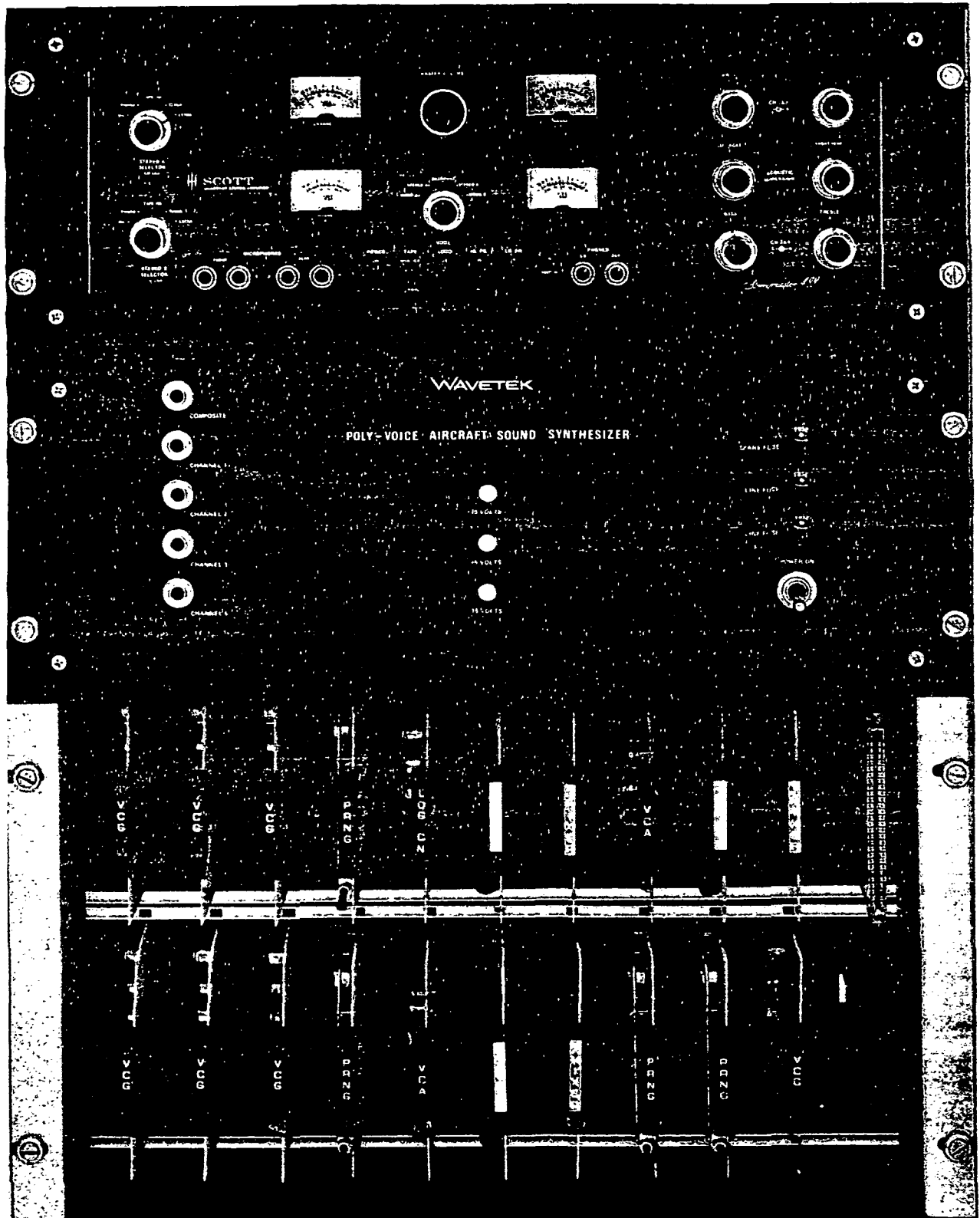
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Figure 3.2.3-12 POLYVOICE SOUND SYNTHESIZER PACKAGING

### 3.2.3.3 External Interface Equipment

SMS External Interfaces between Building 5 and Building 30 include the Block I Trajectory Data interface, the Block II Telemetry interface, The Command (Uplink) interface, the Central Timing System interface and the Voice Communications interface. With the exception of Voice Communications, a brief description of these interfaces is included in the following paragraphs. The Voice Communications System is discussed in Section 3.2.3.5.

#### 3.2.3.3.1 Block I Trajectory Data Interface

This interface presently consists of telephone lines and two sets of Bell System type 301-B Modems transmitting bi-directional data at a rate of 14.2 kilobits per second per line. Reference Figure 3.2.3-13. It is recommended that these modems be replaced by type 303-C modems or others to give bit rates of the order of 50 kilobits per second per line.

#### 3.2.3.3.2 Block II Telemetry Data Interface

The Building 5 to Building 30 simulated telemetry interface presently consists of five coax lines. One FM/VCO utilized for two channels of Skylab analog biomedical data plus four lines transmitting clock pulses and telemetry data from Building 5 to Building 30 at various rates including 7.2 kilobits per second and 36 kilobits per second. Line drivers will be provided in the SMS to interface with two of these lines to provide clocking and telemetry data signals. It should be noted that the Shuttle Vehicle is presently understood to include air to ground telemetry data rates of 128 kilobits per second and 256 kilobits

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MINI COMPUTER  
PDP 11/45

BUILDING 5

BUILDING 30

DP11-DC  
SYNC.  
INTER-  
FACE

DP11-DC  
SYNC.  
INTER-  
FACE

DCU

DCU

301B  
DATA  
MODEM

301B  
DATA  
MODEM

301B  
DATA  
MODEM

301B  
DATA  
MODEM

DCU

DCU

TELEPHONE  
LINES

COAX  
PATCH  
BOARD

FIGURE 3.2.3-13  
BLOCK I TRAJECTORY DATA INTERFACE

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BUILDING 30

BUILDING 5

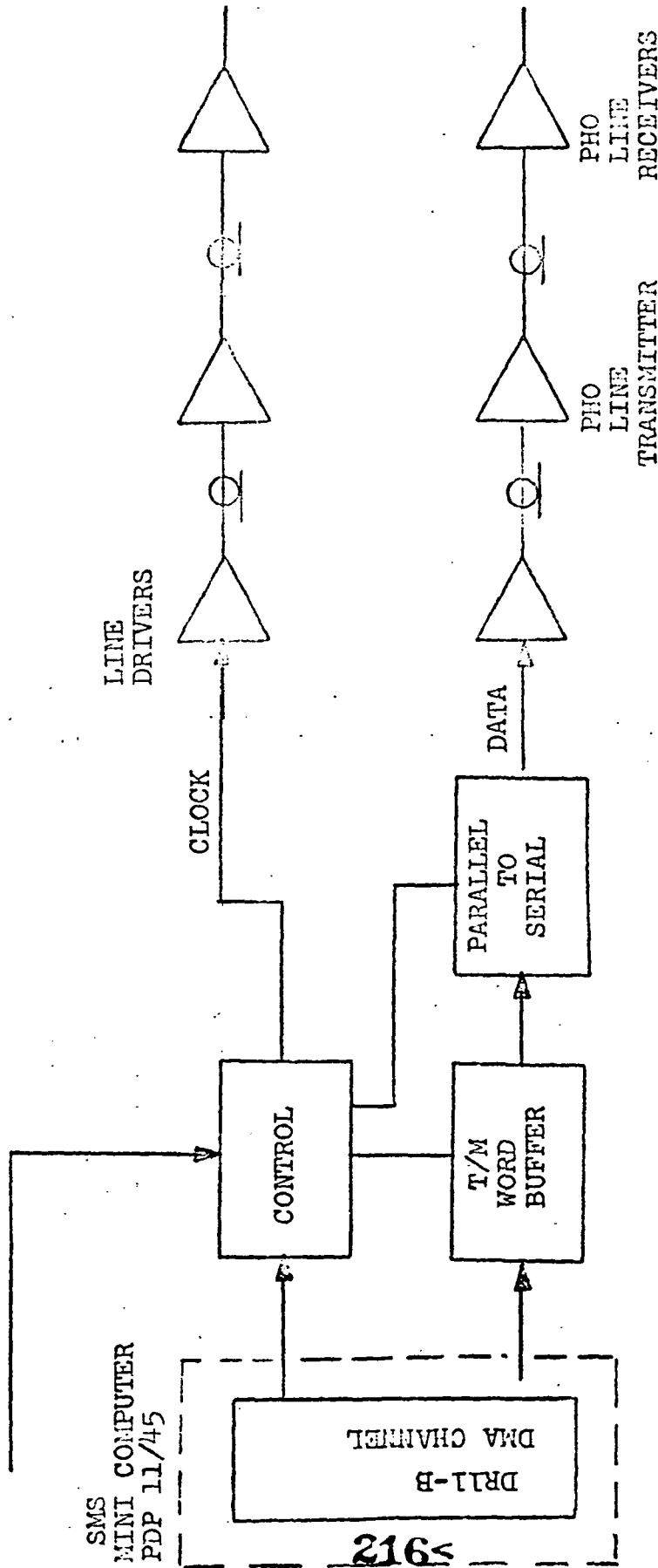


FIGURE 3.2.3-14

BLOCK II TELEMETRY DATA INTERFACE

per second. A complete review of this interface is therefore recommended, with the intent of establishing simulation requirements for both the air to ground and ground to ground sections of the telemetry link. (Refer to Figure 3.2.3-14).

#### 3.2.3.3.3 Command (Unlink) Data Interface

The Command interface consists of four telephone lines from Building 30 to Building 5 transmitting data one way at 2.36 kilobits per second, utilizing a type 201-A modem. Two lines are uplink data and two are clock data. The SMS will interface with these lines in Building 5 to accept the uplink command data. (Refer to Figure 3.2.3-15).

#### 3.2.3.3.4 Central Timing Interface

To enable the Shuttle Mission Simulator to operate in real time synchronism with the Mission Control Center, timing signals will be provided by MCC to enable this synchronization, and consist of the following:

| <u>Frequency</u> | <u>Duty Cycle(%)</u> | <u>Z out</u> | <u>Logic Levels</u>       |
|------------------|----------------------|--------------|---------------------------|
| 1 ppm            | 66 2/3               | 75-90        | 0 $\pm$ 0.5; -6 $\pm$ 0.5 |
| 1 pps            | 80                   | 75-90        | 0 $\pm$ 0.5; -6 $\pm$ 0.5 |
| 1 Mhz            | 50                   | 75-90        | 0 $\pm$ 0.5; -6 $\pm$ 0.5 |

The SMS will utilize these signals to assure time synchronization. Additional details related to the Central Timing Equipment are to be found in Section 3.2.3.4.

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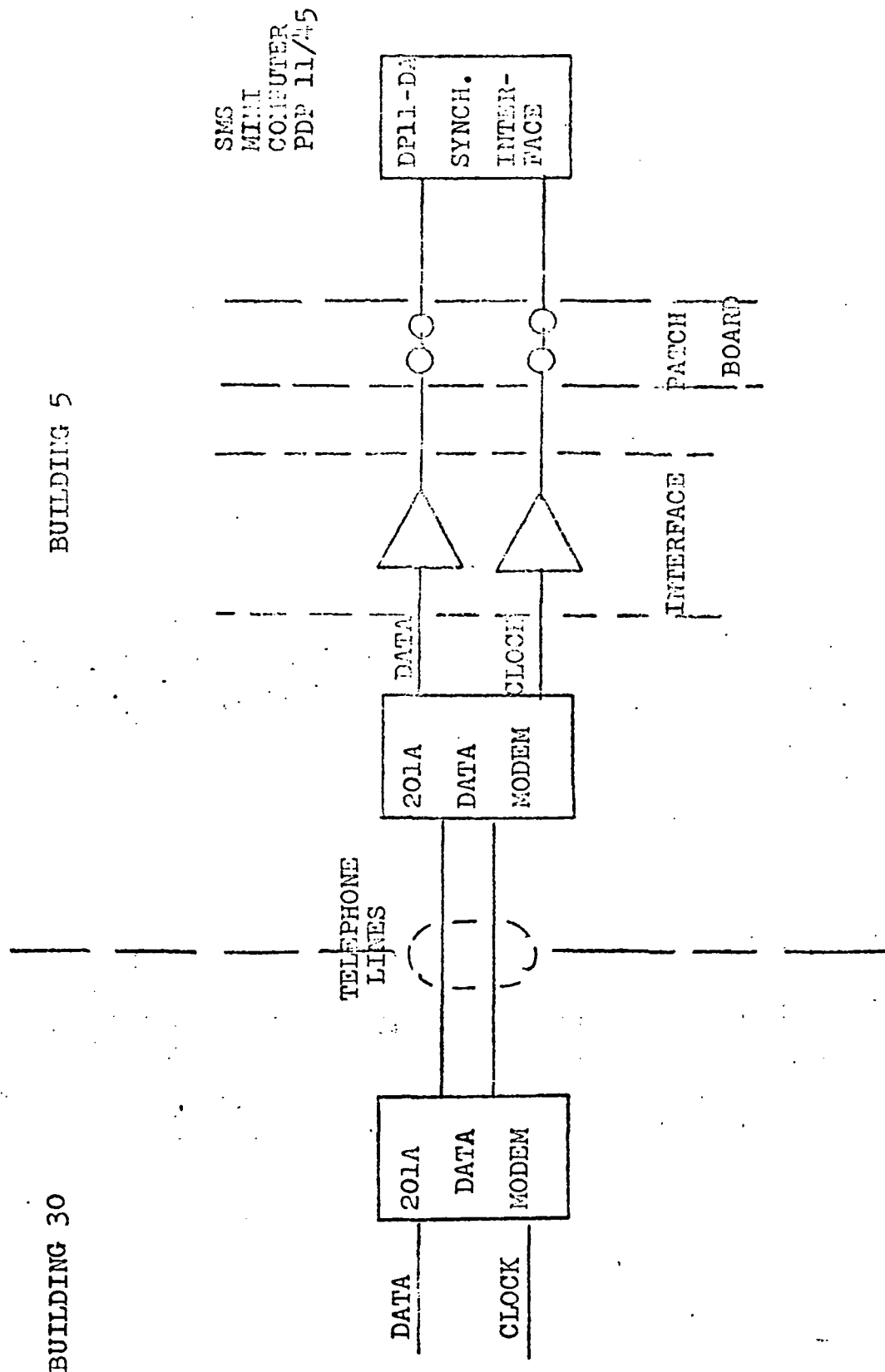


FIGURE 3.2.2-15  
COMMAND DATA INTERFACE

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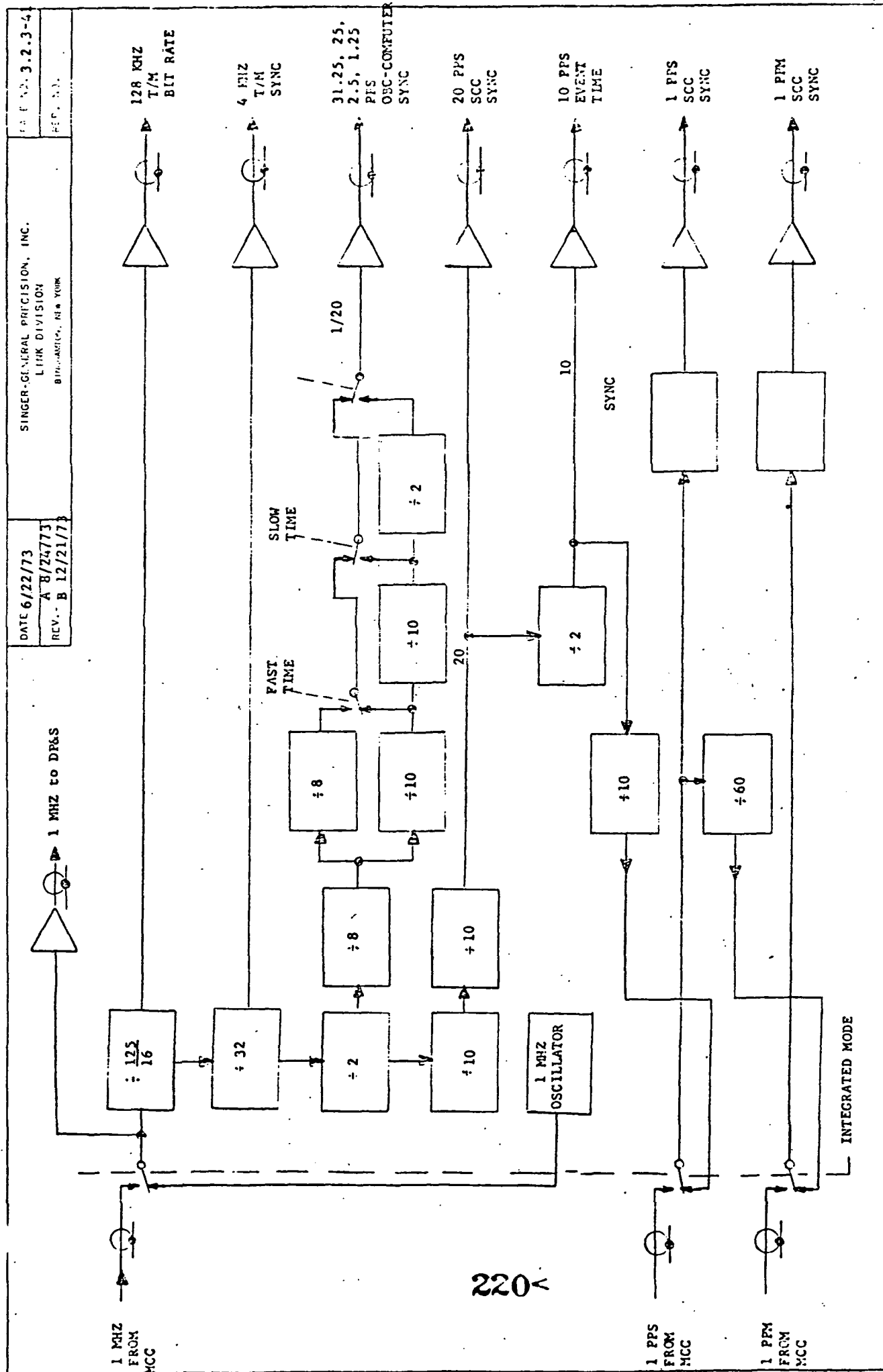
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#### 3.2.3.4 Central Timing Equipment (CTE)

Central Timing Equipment will be provided in the SMS consisting of an oscillator and countdown frequency division circuits to provide basic timing signals of 128 KHZ, 4 KHZ, 25 pps, 20 pps, 10 pps, 1 pps, and 1 ppm. A basic clock frequency of 1 MHZ will be used. In MCC Integrated modes, the CTE will be synchronized with the 1 MHZ timing signals available in Building 5 and identified in Section 3.2.3.3 above. Additional output signals of 31.25, 2.5, and 1.25 pps will be generated for use by the OBC hardware for fast and slow-time sync.

Line drivers, with coaxial lines, properly terminated, will be provided, to provide suitable pulse signal levels and power levels for the synchronized equipment. A block diagram of the approach to the CTE System is shown in Figure 3.2.3-16.

The final design will depend on actual signal frequencies available from MCC and the requirements of the SMS.



**FIGURE 3.2.3-16 CENTRAL TIMING EQUIPMENT**

### 3.2.3.5 Audio Communications System

The audio communications system for the MBCS will include six audio control panels; one at each crew station position. These audio panels will control the transmission and reception of simulated S-Band, VHF-1, VHF-2, and Intercom signals in the crew station. The controls for EXTERNAL communications will not be simulated. In the crew station the relative volume of each incoming signal will be independently variable. A single Master Volume control can also adjust overall volume.

The simulated spacecraft communications networks, six independent astro loops, and 3 maintenance loops, will be provided in the crew station.

Additional control panels will be provided at each instructor station. A communications interface with MCC and MCCSF will also be provided.

The Instructor Station communication control panel function and operation is described in Section 3.2.2.

A separate set of monitor only switches is also provided on the instructor station control panels.

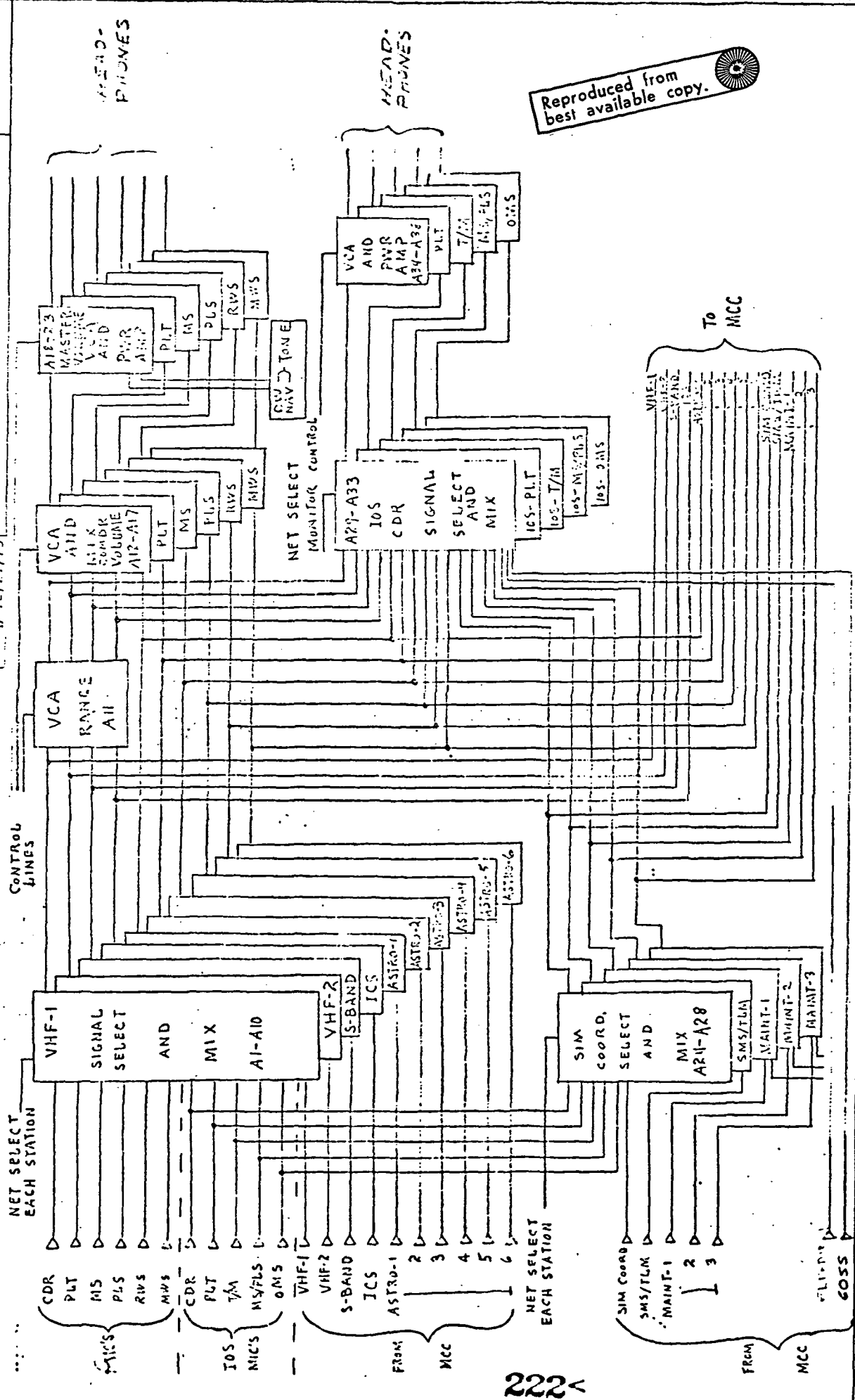
A general layout block diagram is shown in Figure 3.2.3-17. The maintenance interphone nets are shown in Figure 3.2.3-17A.

In addition to the control panels, each crew station and IOS position will be provided with a microphone pre-amp/driver, a test oscillator, and a headphone buffer/receiver amplifier. Signal conditioning, routing, isolating or mixing, and driving will be centralized in the Communications System Cabinet. Components will be primarily of the DIP variety. 221<

FIGURE 3.2.3-17  
BLOCK DIAGRAM AUDIO COMMUNICATION NETWORK

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FIGURE 3.2.3-17A

BLOCK DIAGRAM MAINTENANCE INTERPHONE NETWORKS

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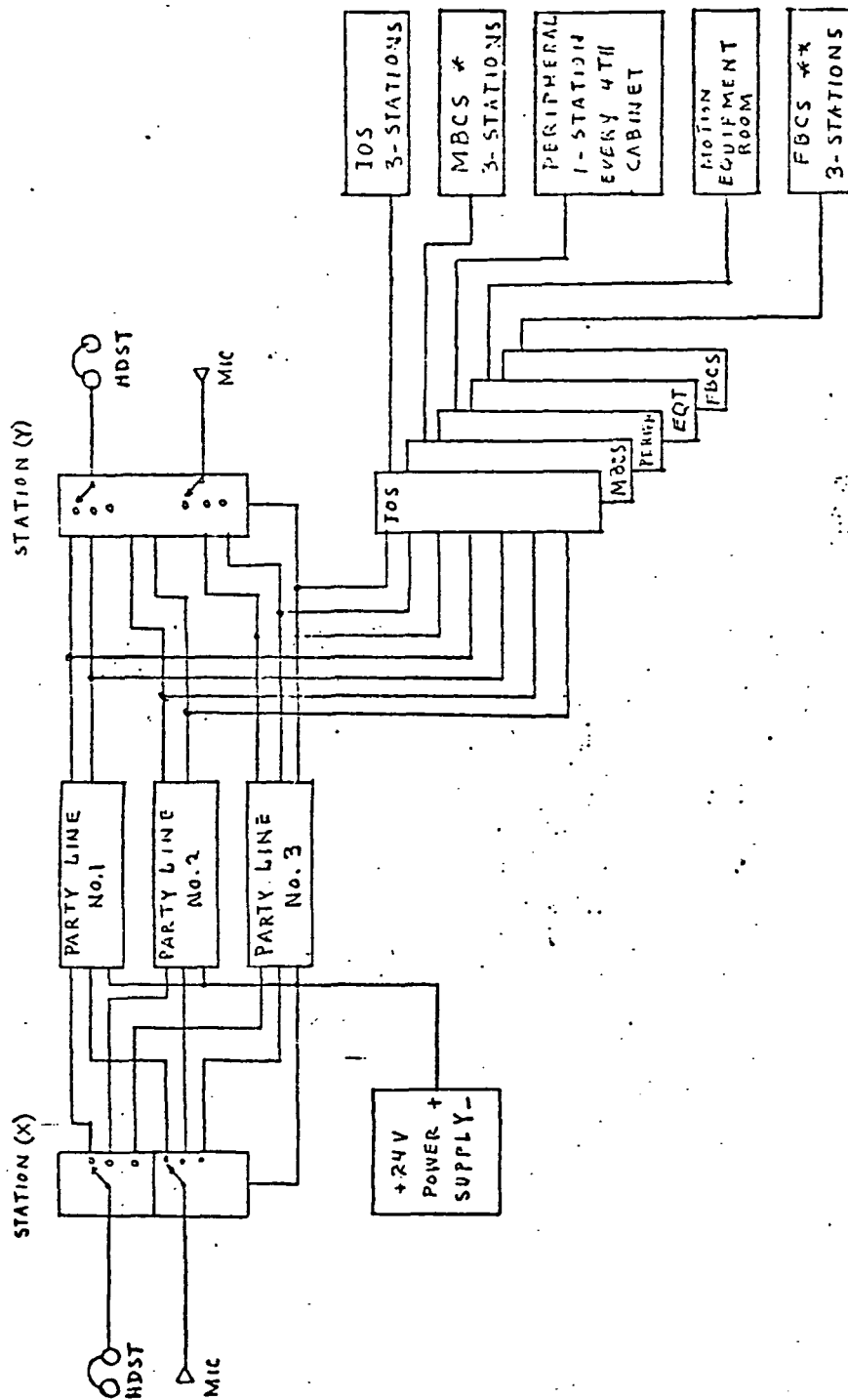
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LINK DIVISION

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All audio signals network selection control signals, and computer/DCE control signals will be routed to this cabinet.

As shown, in Figure 3.2.3-18, the selected signals from the different locations will be mixed and otherwise modified by simulation functions, e.g. range attenuation and provided as network outputs for distribution. Other simulation audio requirements, such as Caution-Warning tones, and Tacan and ILS tone generation, are also included in the equipment.

#### 3.2.3.5.1 S-Band and VHF Communications

Audio communications on the S-band and VHF frequencies will be simulated by a combination of electronic elements including white-noise generators (WNG) and voltage-controlled attenuators (VCA) as shown in Figure 3.2.3-19.

The instructor's transmissions to the crew will be mixed with white noise. The attenuation of noise and signal will be computer controlled via the DCE which will simulate both range and noise level fluctuations.

#### 3.2.3.5.2 Interphone Communications System (ICS)

The ICS will enable all crew members to talk with one another, as well as serving as a communications link to the instructors. All cockpit controls for the ICS will be operative to the extent of switching and volume control functions.

#### 3.2.3.5.3 Simulator Interphone Network

The Simulator Interphone Network, including the Maintenance Intercom System, will be party line system enabling

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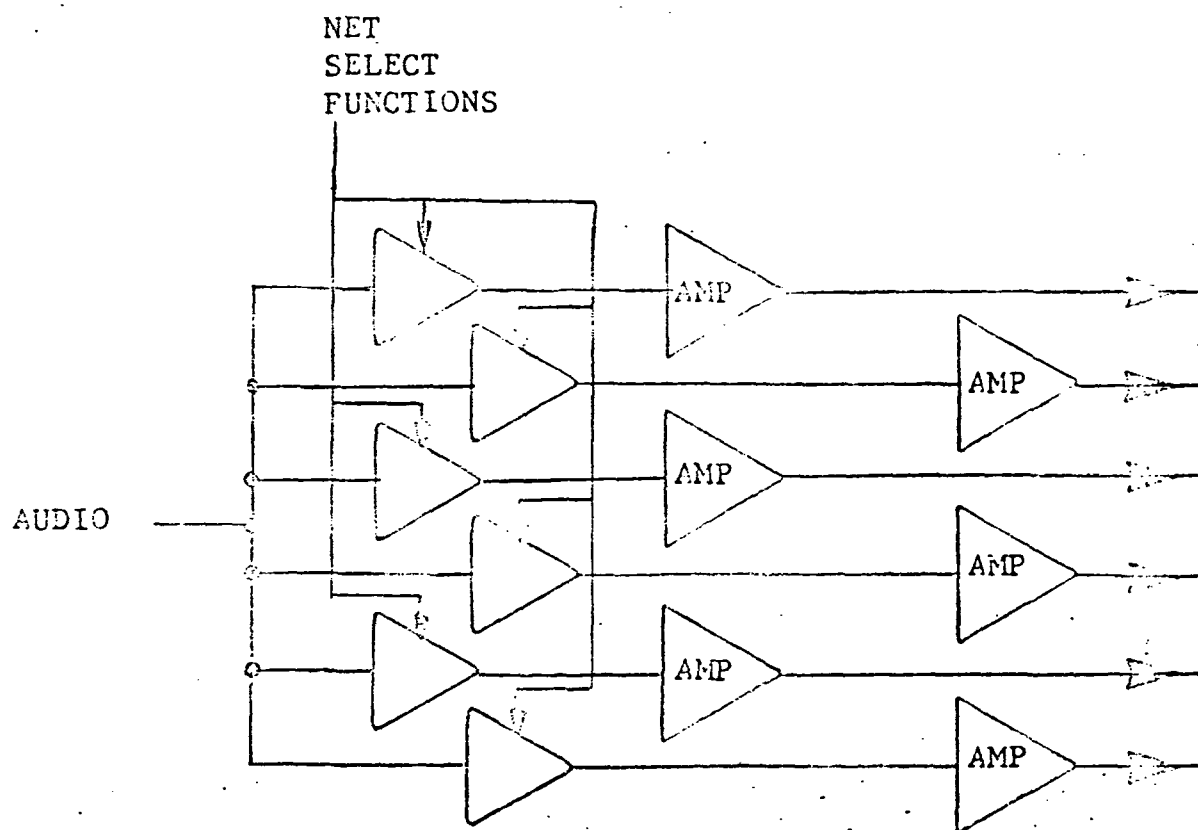


FIGURE 3.2.3-18  
NET SELECT LOGIC

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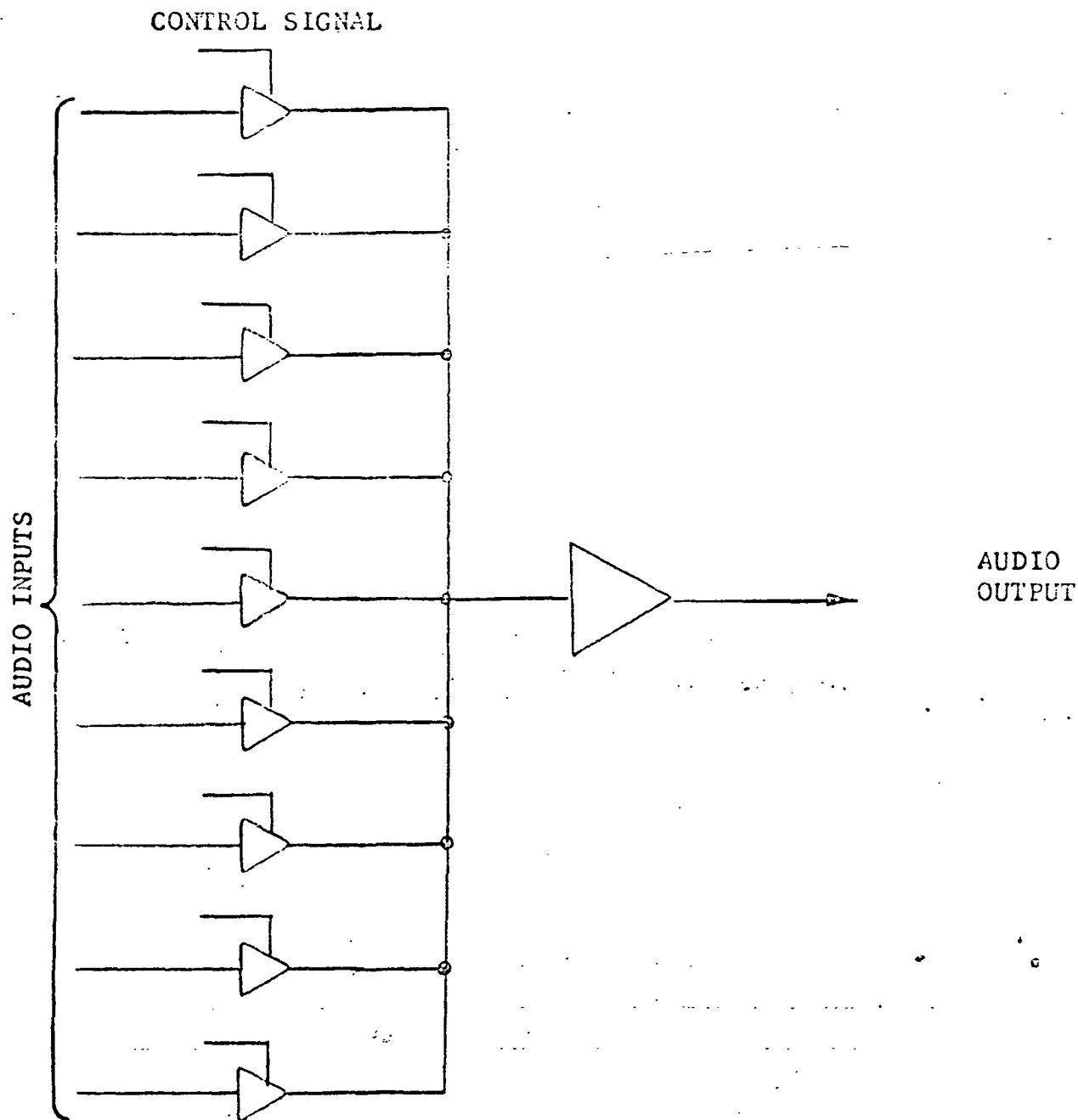


FIGURE 3.2.3-19  
SIGNAL MIXING CIRCUIT

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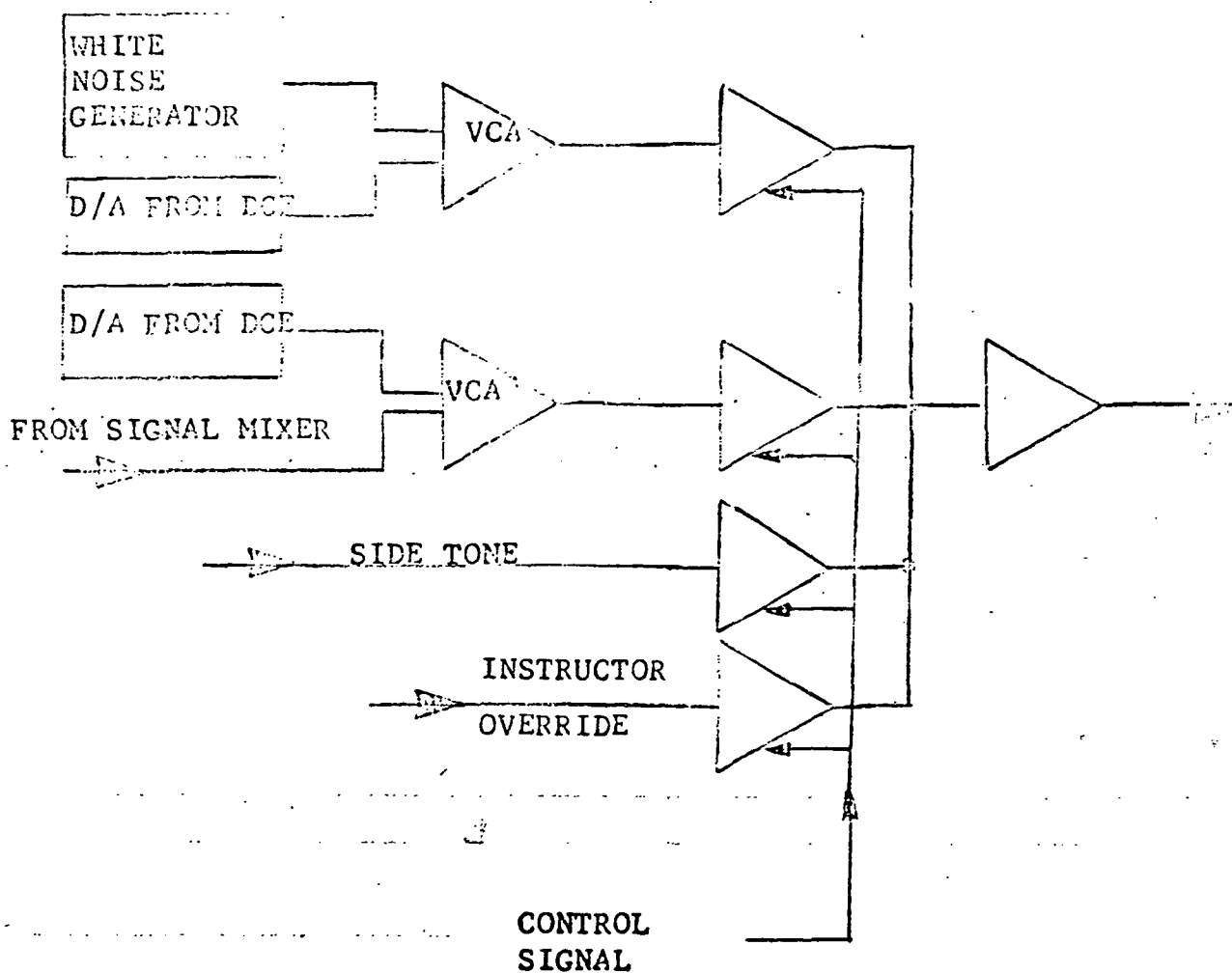


FIGURE 3.2.3-20  
CONTROL AND MIXING CIRCUITS

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communication and monitoring on several channels independent of the simulated real world systems. Channels provided will include the six Astronaut Loops between the IOS and the crew station, the Simulation Coordination Loop, the SMS/TLM Loops, the Flight Director Loop, the GOSS Loop, and three independent Maintenance Loops. These channels will interface with MCC in integrated modes of operation. The Flight Director and GOSS Loops will have a Monitor-only capability, and will only be active in the integrated mode. The system will include an independent power supply, a network of interconnecting cables terminated in jacks and plug-in audio equipment. Strategically placed jacks will accept portable microphone/headset inputs. The audio amplifiers will be self-contained in the units.

Power for the intercom system will be obtained from the utility power distribution network, thus permitting use of the system with the simulator power off. Interconnecting cabling will be of the twisted-shielded type, with single-point grounding at the power supply. Crosstalk and noise will be prevented through design and installation techniques, including the prevention of feedback noises at each station.

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3.2.3.5.3 NAV Audio3.2.3.5.3.1 TACAN

The TACAN tone will be generated by a fixed frequency oscillator (FFO). A computer controlled FET will switch the 1350 HZ tone to generate the desired code. (Figure 3.2.3-21).

3.2.3.5.3.2 ILS

The ILS tone will be developed in the same manner as the TACAN tone except that a 1020 HZ tone will be used.

3.2.3.5.4 Caution and Warning Tones

The caution and warning tones will be generated by a fixed frequency oscillator (1 KHZ). The tones will be fed through computer controlled FET switches to Voltage Controlled Attenuators (VCA) and then summed at an amplifier.

The computer controlled VCA's adjust the volume of the tones while the FET's control the interrupt rate. The desired caution and warning signals can then be chosen by varying the volume levels and the interrupt rates of the tones. (Figure 3.2.3-22).

3.2.3.5.5 Audio Communications System Detailed Design Features

For signal/noise ratio and crosstalk considerations, each mic signal will be stepped up by a gain of 6. Thereafter, all signal manipulation will be at a gain of 1 until the final amplifier stage, which will have a gain of approximately 2.5.

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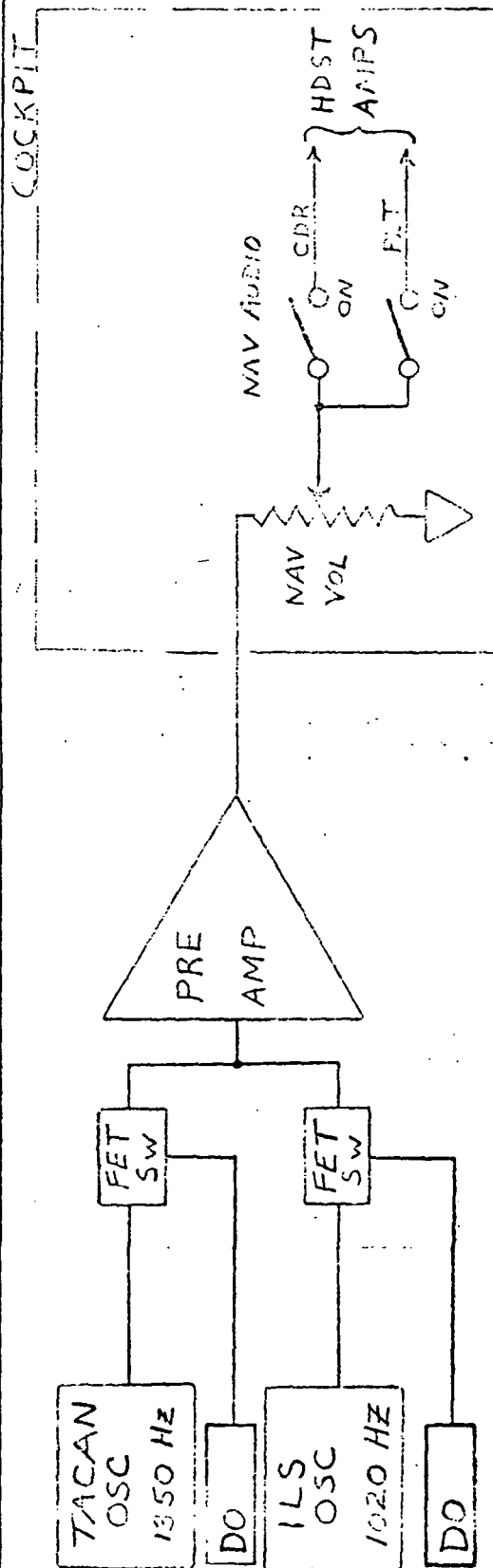


Figure 3.2.3-21 ILS and TACAN Tone Generation

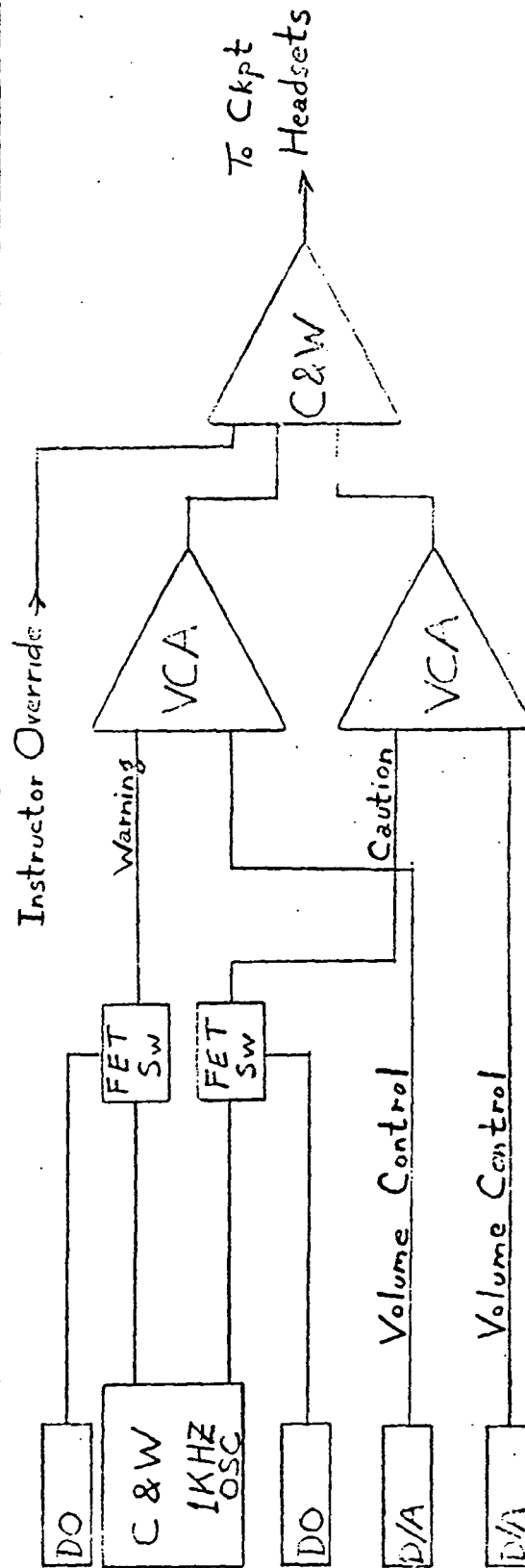


Figure 3.2.3-22 Caution and Warning Tone Generation

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A gain of 1 will eliminate any intermediate variations within the audio system. DC errors due to input bias currents within the op-amps will be negligible. FET analog gates will be used for all necessary audio switching, isolating, and mixing.

The following describes typical circuits of the audio system design. Numbers correspond to those on the illustrations.

1. An audio tone source will be provided for test purposes. The tone will be made available only as desired by switching from a test panel.

2. Mic Pre-Amp/Driver - Although some headsets come with minature amplifiers, it will be necessary to boost the Mic Signal before transmitting it to the Communications System Cabinet.

3. Differential Receiver/Buffer Amps - Signals from the various panel positions to the Communications System Cabinet, and vice versa, as well as MCC's signals, will be terminated in a differential receiver configuration. This will make use of the high common mode rejection ratio of the op-amps to reject common mode voltages such as noise pickup. It also obviates the use of transformers and provides a low impedance source for all using circuits. Figure 3.2.3-24 illustrates more adequately how this circuit will be applied.

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4. Mixer/Driver Amp - This serves to collect the various signals to a particular audio control panel and provides a low impedance driver to the panel positions. Reference Figure 3.3.2-19.

5. Mixer - Many schemes have been employed in the past to switch and/or mix signals, ranging from the use of transformers and relays to discrete FET's. This application of the IH5009 brings together many desirable features; high noise immunity, very low crosstalk (typically 120 dB), constant load impedance, compactness, and ease of cascading. In conjunction with thick film resistors in DIP's, various load impedances can easily be configured as needed. (Figure 3.2.3-25).

6. Audio Amplifier - This configuration will vary little from the suggested application information. The input and feedback components will be scaled to make the overall gain approximately 2.5.

7. Inverter/Buffer - To be consistent with the approach to ground system isolation inverters will be used to isolate the DCE ground from the audio ground system. (Reference Figure 3.2.3-25).

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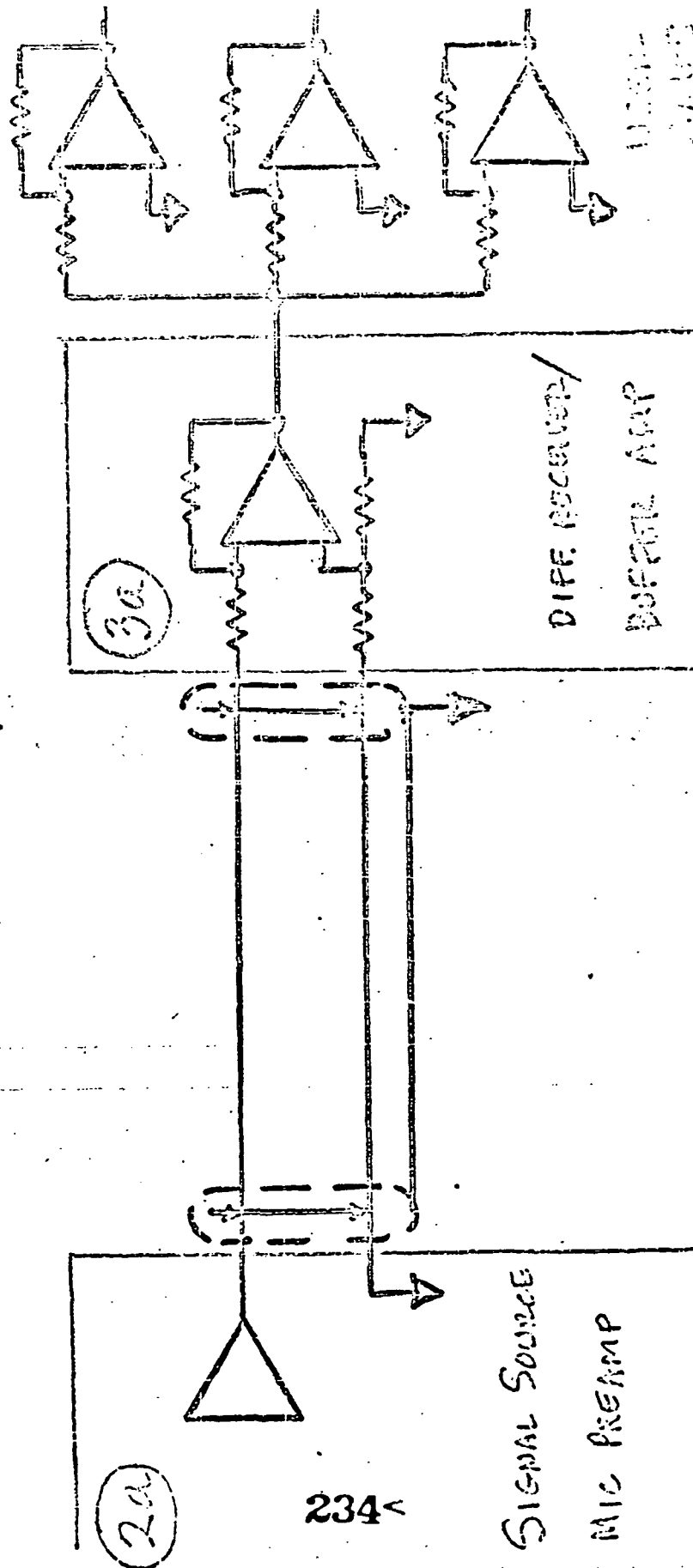


Figure 3.2.3-24  
DIFFERENTIAL RECEIVER BUFFER AMP



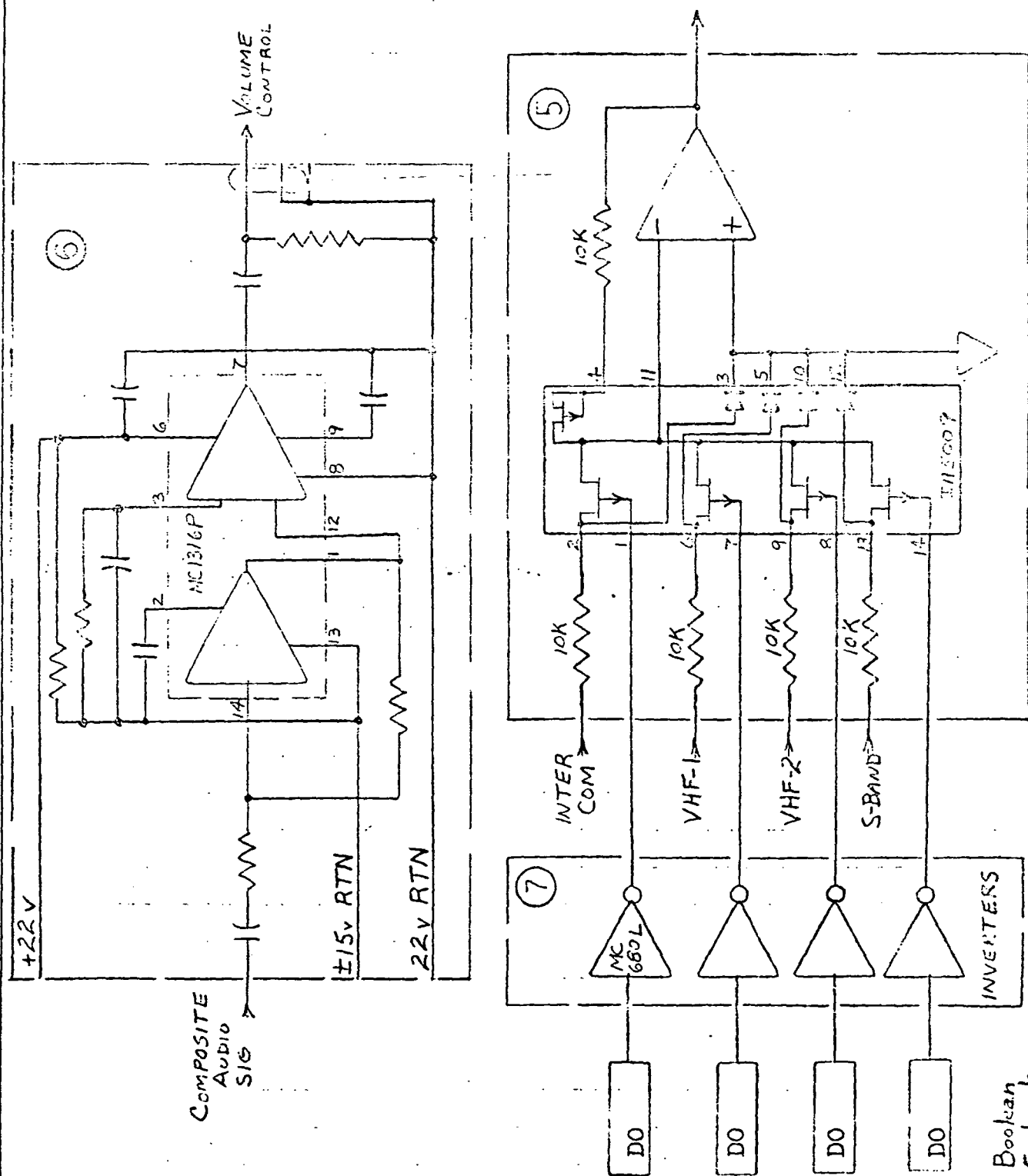


FIGURE 3.2.3-25  
INVERTER AMPLIFIER AND DRIVER WITH 100% DUTY

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### 3.2.4 On-Board Computer Simulation

On-board computers are utilized in two major systems of the Shuttle vehicle.

One subsystem, entitled the Data Processing and Software Subsystem, includes a total of five digital computers operating in conjunction with associated input/output, data conversion, peripheral, and display and control equipment. This system is dedicated to the tasks of primary and backup guidance, navigation and control, subsystem performance monitoring, and payload control for the manipulators.

A block diagram of this system is shown in Figure 3.2.4-1.

Each CPU, manufactured by IBM is a general purpose computer with a basic full word length of 32 bits. Each provides fixed and floating point hardware arithmetic with half and full word operations. Double precision floating point operations are also provided. The computers have a capability of at least 400,000 full word operations per second in fixed point. Memory cycle time is less than 1.8 microseconds. The computer is capable of addressing 128K words within one full memory cycle time.

Each of these computers interfaces with external Space Shuttle Avionics subsystems through an equipment identified as the Computer Input-Output Processor (IOP). All data communications between each computer and external avionics equipment is accomplished through the IOP.

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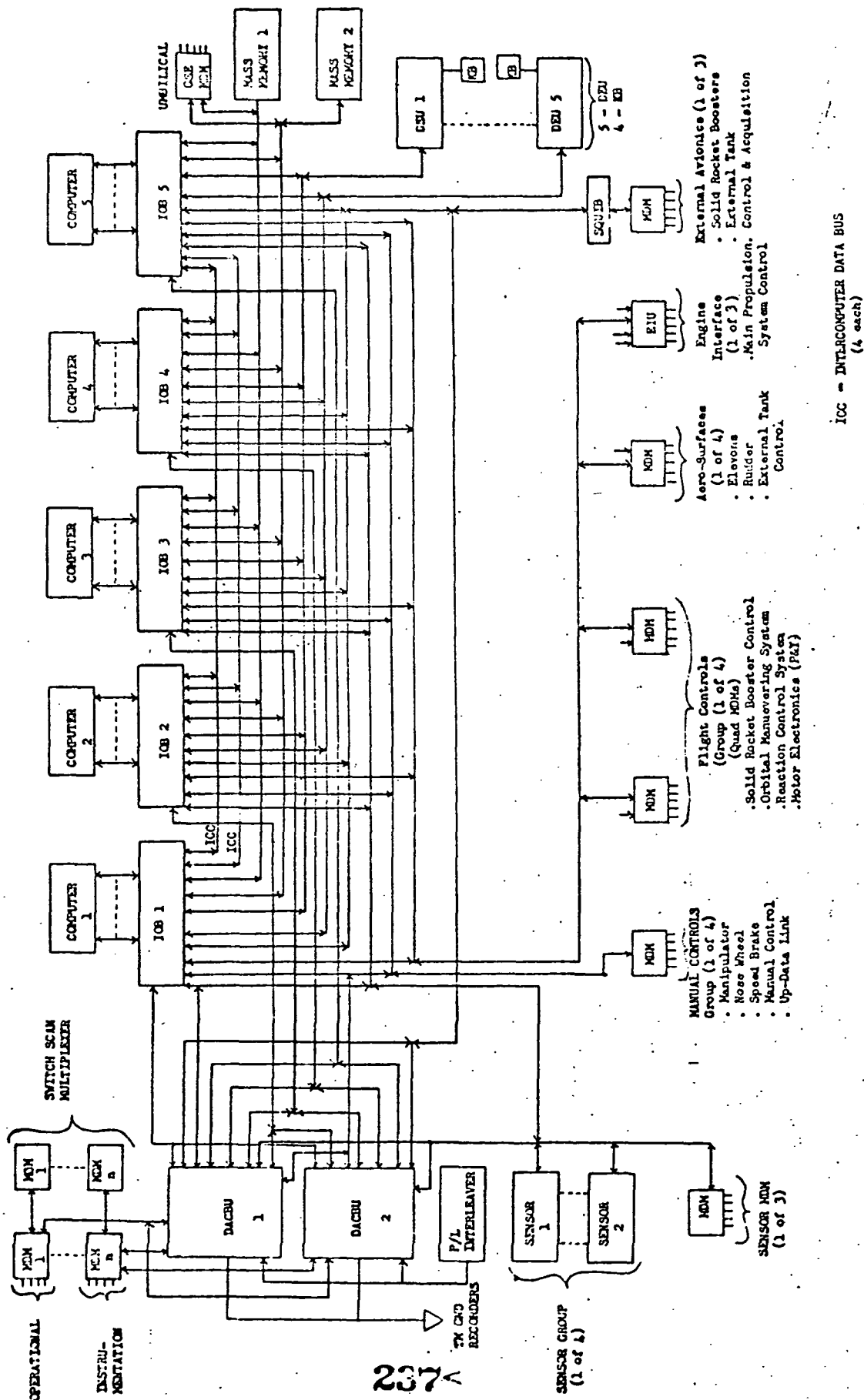


FIGURE 3.2.4-1  
SHUTTLE DP&S SYSTEM BLOCK DIAGRAM

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On the computer side the IOP interface consists of parallel channels for data transfers and address information plus additional discrete input and output lines for other interface control functions.

On the Avionics equipment side the IOP interfaces with the vehicle subsystems via Multiplexed Interface Adapters (MIA). All data communications between the IOP modules and interfacing Avionics Subsystems is in serial format. The data is transmitted to and from the modules in a Manchester II Bi-phase coded serial format at a rate of one megahertz. In the SMS, the crew station CRT display and keyboard elements will be provided as GFE. It will be the responsibility of the SMS contractor to integrate the equipment into the crew station and IOS station.

The second Shuttle system incorporating on-board digital computer is the Main Engine Control system where a total of six Honeywell HDC-601 computers are employed in a redundant fashion for control of the firing and gimbaling of the three main engines.

A block diagram of this system is shown in Figure 3.2.4-2.

The HDC-601 includes a 16-bit parallel binary, two's complement arithmetic unit and a plated wire memory with a cycle time of one microsecond. In function and operation the HDC-601 is identical to the Honeywell H-516 digital computer.

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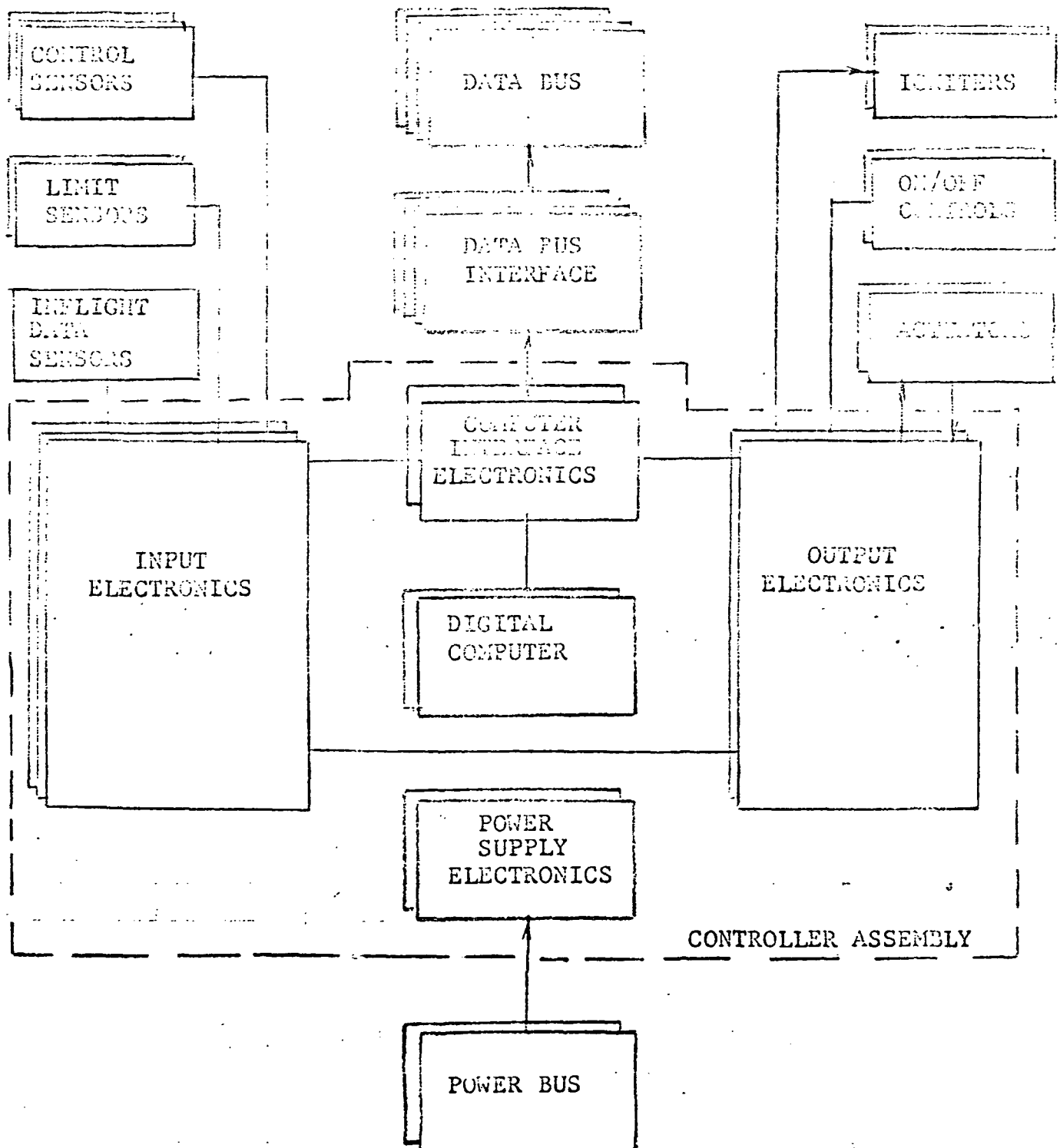


FIGURE 3.2.4-2  
ENGINE CONTROLLER FUNCTIONAL RELATIONSHIPS

### 3.2.4.1 Simulation Requirements

#### 3.2.4.1.1 Data Processing and Software Subsystem

The simulation of the Data Processing and Software subsystem of the Shuttle Vehicle is required to the level that all crew display data and telemetered data responses are extremely realistic for both displayed value and time response to interface signals, commands and switching logic, and simulator modeling. Both the short period and long period accuracy of the simulation must be very high to maintain astronaut confidence in the simulated system and avoid negative training in the use of the system. This will be particularly true during M.C.C. integrated mission training where outputs of the ground computer system are compared with the calculations made in the simulator. Hence the requirement for use of actual OBC flight programs, and an accuracy no less than that of the actual on-board computers. In this case, a 32-bit computer should be utilized for the simulation.

As a minimum, the actual crew station display and control equipment should be used in the simulator to ensure high fidelity display and control. This should include the dual redundant tape readers, if crew procedures dictate the requirement for loading and operating these devices.

The simulated Data Processing and Software subsystem must also interact with the simulator mode functions without degradation.

The reset function in the simulator is provided to enable rapid

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return and restart at mission time points where extensive training is required while skipping over time periods of low activity.

The astronaut should be able to select the DP&S Computer System Operational Mode and realize the same effects as in an actual flight. The requirement to simulate redundancy effects occurs in conjunction with the requirement for simulated malfunctions to train in all backup modes of operation. Simulated malfunctions should be chosen based on failure analysis of real world equipment coupled with the desire to train the astronauts in all backup modes and highly critical procedures to ensure their safety in the real flight.

Use of actual OBC flight software is necessary for reasons of simulation fidelity and to avoid delays inherent in the functional simulation software development and test/verification processes. It is anticipated that software changes to the DP&S Computer programs will occur with very short notice. Therefore, the simulator software should be capable of being rapidly updated and reverified, and any equipment or software required to expedite this operation should be provided.

#### 3.2.4.1.1.2 Main Engine Controller

The simulation of the Main Engine computer programs should be of equivalent accuracy, resolution, and iteration rate as in the real world. Data rates and formats to recorders and to the Telemetry system



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must be simulated with high fidelity.

The main engine computer simulation must interact with the simulator mode functions without degradation.

Simulation of the redundancy features is also desired to enable training in backup modes and procedures by inserting malfunctions of one or more elements of the engine controllers.

Selected elements of each engine controller will be malfunctioned to provide crew and MCC training in backup modes and procedures.

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### 3.2.4.2 Simulation Approaches

Several methods of real time simulation of airborne and aerospace vehicle on-board computers have been examined in the light of Shuttle vehicle requirements. Techniques which have been considered include the use of real (or equivalent non-flight qualified) computer hardware, translator/compiler, interpreters, functional simulation, and emulation. A brief description of each of these techniques with the advantages and disadvantage of each is discussed in the following paragraphs.

#### 3.2.4.2.1 Real Hardware

Use of real (or functionally identical non-space rated) on-board computers in a training device is possible but must include interface hardware to allow communication to and from the main simulation computer(s) and may also require additional specialized peripheral equipment for computer loading and I/O to associated displays and controls. Advantages in the use of an actual (or functionally identical) OBC are as follows:

- (1) The CPU time and core memory loading requirements in the main simulation computer will be reduced.
- (2) Flight programs may be used without modification.
- (3) New modified flight programs can be loaded at any time with a minimum of modifications to the main simulation computer load.

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(4) The effort necessary to maintain correct documentation and configuration control for changes in the flight programs is also minimized.

Use of the real OBC hardware requires the design and development of special interface hardware. This interface hardware may be complex and include signal level conversion equipment, parallel and serial data channels, buffer memories, and time synchronization hardware depending on the complexity of the OBC I/O and the compatibility with the main simulation computer I/O interfaces. Cost, availability, and delivery schedules of the OBC and interface hardware may be prohibitive. Additional software may also have to be added to the OBC to permit its function in a simulation environment.

Computer hardware functionally identical to the actual flight hardware is presently being used on the Skylab Apollo Telescope Mount Digital Computer (ATMDC) Simulator. The computer used is a non-space rated IBM System 477 Model TC-1 computer with interfacing to an IBM Model 360.

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### 3.2.4.2.2 Translator

In a translative simulation of a computer, the actual flight program must be preprocessed to convert the flight program to an equivalent simulation computer program. This technique differs from the interpretive simulation in that the instruction decoding is done off-line and each OBC instruction is replaced by one or more simulation computer instructions to perform the same operation.

A translative simulation offers many of the same advantages as use of real OBC hardware in that the simulation is based on the actual flight program coding. Translation is faster in real-time execution than interpretation because the burden of decoding an OBC instruction and substituting simulation computer coding is handled by off-line preprocessing. New modified flight programs may be translated and loaded at any time with negligible effect on the main computer load. Effort necessary to maintain documentation and configuration control for changes in the flight program would be minimized. The translative approach also offers the opportunity for validation of the translated program by comparing its performance with the flight program. Input data used during test runs on the flight program could be made available for similar runs on the translated program. A comparison of outputs from the two programs could be used for detecting errors.

A translative simulation is only feasible if the OBC instruction and the simulation computer instruction sets are similar enough

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to permit translation without an enormous increase in required core memory or impact on execution performance. In addition, the host computer must be sufficiently faster than the OBC which is being simulated to compensate for the increase in code volume brought about by the translation.

### 3.2.4.2.3 Interpreter

In an interpretive simulation of an on-board computer, the simulation computer must accept an actual OBC flight program as a data set. The host computer must then execute that flight program "interpretively". The interpretive simulator program must decode each OBC instruction sequentially in real time and then execute a set of host computer instructions to duplicate the requested action. In its purest form an interpretive simulation requires the dedicated use of the host computer. Ideally, this host computer must also be compatible with other computers in the simulation computer complex.

An interpretive simulation of an OBC offers several of the same advantages as use of the real OBC hardware.

- 1) Flight programs may be used without modification.
- 2) New modified flight programs can be loaded at any time with only slight modification to the main simulation computer load.
- 3) The effort necessary to maintain correct documentation and configuration control for changes in the flight program is minimized

The interpretive simulation also provides an opportunity for

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effective validation of the interpreted program by comparing its performance with that of the actual flight program. The input data used during test runs on the flight program could be made available for similar runs on the interpreted program. A comparison of outputs from the two programs could be very useful in detecting errors.

In its purest form, an interpretive simulation requires the dedicated use of a host computer. Thus, one or more digital computers must be added to the simulation facility.

The interpretation process for a single OBC program instruction requires that the computer load the instruction, isolate and interpret the operation code, and decode the operand address based on the interpretation of the operation code. Then the interpreter must execute one or more instructions to perform the function intended by that OBC instruction. Therefore, the host computer must be several times faster than the OBC which it is simulating. The development cost of such an additional computer with special modifications plus the cost of interface hardware may be prohibitive.

The interpretive simulation technique has been used with considerable success to simulate the Block II AGC and LM guidance computer in CMS and LMS simulators.

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#### 3.2.4.2.4 Functional Simulation

Developing a functional simulation of an on-board computer requires:

- a) an in depth analysis of the OBC computer hardware and the programs which it executes.
- b) creating mathematical models describing the hardware function and the programs, and their interaction.
- c) programming effort to convert the mathematical models to computer programs in the language of the simulation computer.
- d) testing and verifying these programs, independently and in conjunction with the other simulation programs and with associated control and display hardware.

A functional simulation is characterized by the requirement for simulation data in a well defined form available early in the simulator development program. Data which identifies changes to the OBC programs must also be available a fairly long period of time before these must be available for flight crew training.

Functional simulations of on-board computers have been successfully achieved on a wide range of military and commercial aircraft simulators including the C-130, the F-4 and F-111 series, and the AJ37 military aircraft, the Boeing 707, 747, and the Lockheed L-1011 commercial airliners.

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### 3.2.4.2.5 Emulation

Emulation of one computer in another has been considered as a method for the simulation of the DP&S and Main Engine Controller computers in the SMS. Although a software approach to emulation has been rejected because of the inherent inefficiencies, simulation using micro programming techniques is still to be considered as a viable approach.

In the truest sense all applications of the micro-programmed computer can be considered emulation. However, as defined here, the emulator computer is the microprogrammed computer with its firmware allowing functional duplication of another computer. Direct emulation of a pre-existing general purpose or special purpose computer is practical only if an advantage results. Usually a cost advantage is realized if the pre-existing computer is several years old. In many cases a speed advantage will result.

Many parameters need be considered to determine feasibility and efficiency of a microprogrammed computer emulating any specific general purpose or special purpose computer. Essentially these parameters are:

- Complexity and Number of Logical Elements.
- Word Size and Number of Hardware Registers.
- Maximum Main Memory (Core) Size and Word Length.
- Execution Time Required Per Operation.
- Input/Output Requirements.

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Detailed knowledge of both the pre-existing computer and the microprogrammed computer is needed to properly evaluate the feasibility and fit of emulation.

Advantages of microprogramming are:

- a) Provides an orderly method of implementing modifications and extensions to existing processor instructions sets.
- b) Permits easier processor trouble shooting through minimization of random logic.
- c) Permits optimum tailoring of computer systems to a specific task by implementing frequently used operations in micro-instructions.
- d) Microprogramming can increase system speed.

Microprogrammable computers are faster than fixed instruction computers for the following reasons:

- 1. Instruction execution times are from 5 to 30 times faster in a microprogrammed computer.
- 2. File registers can be used for data storage, and pointers, where core is required in a fixed instruction computer, thus program execution time can be reduced by avoiding memory access cycles.
- 3. Subroutines are closely tailored to specific requirements and data word lengths, thus improving computer efficiency and speed.
- 4. Input/output routines can be simplified for the application to increase I/O speed.

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5. Special time-consuming algorithms (math, logic, etc.), which are not available in the general purpose processor can be easily incorporated into a microprogrammed processor.

e) Memory space can be reduced.

In the general purpose fixed instruction computer, the instructions are stored in core memory along with data. Both instructions and data can be altered by the program. In a microprogrammable computer, the instructions are stored in a read only memory along with permanent (or constant) data. Only variable data, pointers, and flags are stored in core memory. In the general purpose fixed instruction computer there is usually a limited instruction repertoire with variations of instruction, and memory reference instructions having limited addressing modes. In the microprogrammable computer there is usually a smaller number of instructions, which are more compact and specialized than the fixed instruction computer. Memory addressing and I/O functions usually are built up by assembling a group of microinstructions. The microinstructions are closely related to the internal architecture and I/O structure of the basic computer.

Disadvantages of microprogramming relate primarily to cost and time. Considerable cost is involved in the hardware investment, primarily for new control store hardware. In addition there are time requirements for a microprogrammer to acquire sufficient knowledge to be able to generate micro code, and then to write, debug and implement microprograms. Also to be borne in mind is the fact

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that much existing software will require modification to recognize new function codes.

Microprogramming is still going through some major evolutions which will make it more and more the most important system architectural tool. The ultimate promise is the natural language computer. High level programming languages such as FORTRAN, COBOL, PL-1 and JOVIAL and application oriented languages can be interpreted directly without compilers and assemblers. Programming and operation of a system and debugging a program then becomes highly simplified and more efficient, and thus much more economical.

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3.2.4.3 Tradeoffs and Recommendations

Historically, use of real world hardware in simulators has been characterized as providing a very high fidelity simulation capability. Associated with this fidelity has been a high initial cost. This cost is primarily the sum of the computer plus interface hardware design, interface material, and the effort for interface software development. If more than one simulator is built, a large percentage of this cost is recurring. The non-recurring costs relate primarily to design of interface equipment and the software development. Since the interface requirements are usually well defined, it can be stated that the technical risk involved in this approach is low. The major risk lies in scheduling to have flight programs available in time for Simulator Test and Crew Training.

The translative approach to DP&S simulation is also applicable to the SMS and its appeal becomes greater as higher level language comes into use for OBC programming. Costs of the translative approach to simulation include the required simulation computer hardware (CPU time and memory) plus the non-recurring costs of translator software development. The risk must be considered to be higher than when using real hardware but less than that for the interpretive approach.

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As in the real OBC hardware approach, a major constraint to the translative simulation approach is the availability of flight programs. This software must be available in time to test the simulator prior to crew training. Extra care must be taken in the choice of simulation computer to ensure that special anomalies in the OBC are not the source of impossible to solve problems. The simulation computer must be several times as fast as the OBC to allow real time simulation.

The interpretive approach to OBC simulation is also applicable to the SMS OBC simulation. Costs of the interpretive simulation can be attributed to the dedicated computer and interface hardware plus the non-recurring costs of interpreter software and interface software development. If, as appears likely, a special processor is required, additional logistic requirements are also imposed. From an overall simulation viewpoint, it is believed that an interpreter is more difficult to implement than a translator, and is considered to be less efficient in terms of total CPU time and memory required. As for the real hardware approach and the translative approach, the interpreter approach to OBC simulation requires flight programs in time for simulator test and crew training. Again, as for the translative approach

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the computer dedicated to the interpreter must be several times faster and have a larger memory capacity than the OBC which is being simulated

The functional simulation approach is attractive from the viewpoint of total simulation development. Where OBC flight programs are relatively firm, and only minor changes are anticipated, it may prove to be the most cost effective approach. This method requires no special interface hardware, permits a minimum total computation system load, and can be more adaptable to pre-established frequencies of solution. It is the most straight forward to develop and debug, and has the highest probability of real time execution. However, a functional simulation of the on-board computer requires an in depth analysis of the task and a detailed programming effort to model that task in the simulation computer. Full advantage must be taken of the simulation computer programming features to insure a fast and efficient functional simulation. Excessive turn-around time may be required to implement changes to the simulated OBC program when changes to the operational OBC flight program occur.

Emulation using a microprogrammable computer is a very attractive alternate to the use of real hardware if the approach can be shown to be cost effective, and the technical risk is low.

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As indicated in section 3.2.4, the Space Shuttle vehicle incorporates a total of 11 digital computers of at least two different types in the Data Processing and Software System and in the Main Engine Controllers.

For each of these systems, a tradeoff study is required to determine the optimum simulation method.

The basis for these tradeoff studies must include such factors as data requirements vs availability and changeability, training requirements and training value, and the impact on total simulation cost, complexity, scheduled delivery, and simulator availability of these factors and other factors such as:

- . Logistic Support Requirements, including Ground Support Equipment and Spare Parts
- . Testing Requirements
- . Maintainability, and Reliability, MTTR, and MTBF

It has been established that the computers to be used in the Data Processing and Software (DP&S) Subsystem of the Shuttle Vehicle will be programmed using a high level language (HAL) and that an additional HAL compiler will also be developed for use with an IBM 360 computer. In addition, the DP&S software, including the assembler, Link Edit and Interpretive Simulation Programs are also required to run on an IBM 360/75 computer.

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It can be assumed that a similar compiler can be developed for the SMS Simulation Computer Complex with equivalent efficiency in terms of CPU memory and time requirements.

Estimates have been made of the non-recurring and recurring costs of simulation for both the DP&S subsystem and the Main Engine Controller Computers for the various techniques under consideration.

Based on these costs, risks, and the other factors previously mentioned, the number of viable techniques for the DP&S system simulation has been reduced to one; (Real Hardware, or (alternately, a Micro programmable computer emulator). The translative and interpretive approaches have been rejected because cost, risk and development time are considered extremely excessive. A functional simulation of the DP&S System has been also rejected because of the high costs and high probability that program data will not be available and will change very rapidly. Currently available NAR schedules for the DP&S subsystem software indicate that flight software will not be available until sometime during the MBCS integration phase.

For the two crew station complex specified for the SMS, the hardware approach can be shown to be technically best.

Since it also involves the least amount of risk, and other factors are relatively equal, it has been chosen as the recommended simulation approach for the SMS.



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Investigation of microprogrammable computers for the DPMS system simulation has to date revealed only one computer now in production which is possibly capable of the task. This is the Control Data 5600. Other computers investigated were Digital Scientific, Hewlett-Packard, Interdata, Microdata, and Varian. In all of these cases, word length, memory size, and/or computation speed capabilities prohibited their use in the SMS application.

The CDC 5600 has memory growth capabilities to 262K words or 36-bit word length, and as can be seen in Table 3.2.4-2, it is comparable in execution speed to the IBM Model AP-101.

Further investigation of the CDC 5600 computer will be carried out during the extension period of the SMS Study program.

For the Main Engine Controller Computers, the programming language will in all likelihood be DAP-16, the assembly language for the Honeywell HDC-601, DDP-516 and Type 716 general purpose computer family. Either the translative approach or the interpretive approach to simulation would require a costly and time consuming software development effort. Therefore, both the translative and interpretive techniques have been rejected. The real hardware or a functional simulation approach are considered viable. However, the costs of simulating the Main Engine Controller Computer using non-flight qualified hardware are greater than for the functional simulation. Therefore a functional simulation of the Main Engine Controller has been chosen.

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| INSTRUCTION                                | % USAGE | AP-101                        |        | 5600                           |       |
|--|---------|-------------------------------|--------|--------------------------------|-------|
|  |         | TIME                          | % T    | TIME                           | % T   |
| LOAD/STORE                                 | 50.     | 1.65                          | .825   | 2.0                            | 1.000 |
| ADD/SUBTRACT FIXED POINT                   | 7.      | 1.65                          | .1155  | 3.0                            | .210  |
| MULTIPLY, FIXED POINT                      | 1.      | 5.45                          | .0545  | 5.8                            | .068  |
| DIVIDE, FIXED POINT                        | 0.5     | 8.65                          | .04325 | 12.4                           | .062  |
| ADD/SUBTRACT FLOATING POINT                | 9.      | 2.65                          | .2335  | 3.2*                           | .288  |
| MULTIPLY, FLOATING POINT                   | 3.      | 5.45                          | .1635  | 9.0*                           | .270  |
| DIVIDE, FLOATING POINT                     | 0.5     | 8.65                          | .04325 | 12.4*                          | .062  |
| LOGICAL (AND/OR)                           | 7.      | 1.65                          | .11555 | 2.0*                           | .140  |
| SHIFT                                      | 7.      | 1.6 <sup>M</sup> <sub>6</sub> | .208   | 1.0 <sup>N</sup> <sub>18</sub> | .1155 |
| JUMP                                       | 14.     | 1.10                          | .154   | 1.3                            | .182  |
| AVERAGE INSTRUCTION TIME<br>(MICROSECONDS) |         |                               | 1.961  |                                | 2.282 |

\* ESTIMATED  
(N=NUMBER OF SHIFTS)  
(ASSUME N=8)

TABLE 3.2.4-2

DP&amp;S COMPUTER EXECUTION TIME COMPARISON

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#### 3.2.4.4 SMS DP&S and Main Engine System Baseline Simulation Techniques

##### 3.2.4.4.1 General

Based on data available at this time, one approach to the simulation of the DP&S subsystem and Main Engine Controllers and Main Engines has been developed.

The simulation system incorporates a group of Minicomputers and additional real flight hardware to perform the simulation.

In order to provide this baseline SMS simulation approach, certain assumptions were also made relative to DP&S subsystem operation and simulation requirements as follows:

- a) The simulation of the Launch-Boost phase will not be required simultaneously in the MBCS and in the FECS. Therefore the simulation programs for the Main Engine Controllers and Main Engines may be time shared between the MBCS and FBSC by appropriate switching or multiplexing of data.
- b) Payload Handling simulation is not required in the MBCS.
- c) The operation of the DP&S subsystem computers is such that a maximum of three computers redundantly perform the GN&C function, one provides the system performance monitoring function, and one performs the payload handling function.
- d) The IBM Model AP101 computers, the mass memories, the Display Electronics Units, keyboards and crew station CRT display devices will be GFP.

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e) The DP&S computers have sufficient spare operating time to allow a fast time operating mode at up to 2.0 times real time.

f) For evaluation purposes, the SCC Host computer is assumed to be an IBM Model 370.

Figure 3.2.4-3 is a block diagram of the revised baseline SMS system. As indicated, a total of five PDP11/45 Minicomputers and nine (IBM Model) AP101 on-board computers, with associated memory, interface, and display hardware are included.

To simulate the DP&S subsystem, one PDP11/45 and four AP101 computers plus two mass memory units and four Display Electronic Units keyboards and CRT displays are incorporated in the MBCS. An additional PDP11/45 and five AP101 computers, plus two mass memory units and five DEU, keyboards and CRT are incorporated in the FBCS.

Three more PDP11/45 Minicomputers are provided to perform functional simulation of the main engine controllers and main engines. Each PDP11/45 will include 32K MOS solid state memory, and interface hardware as shown.

Each computer will also include a programmable real time clock, a memory segmentation unit, floating point hardware, and an LA30 DEC Writer terminal.

The interface with the Host computer is a Model DX11B-PDP11 to IBM 360/370 channel interface.

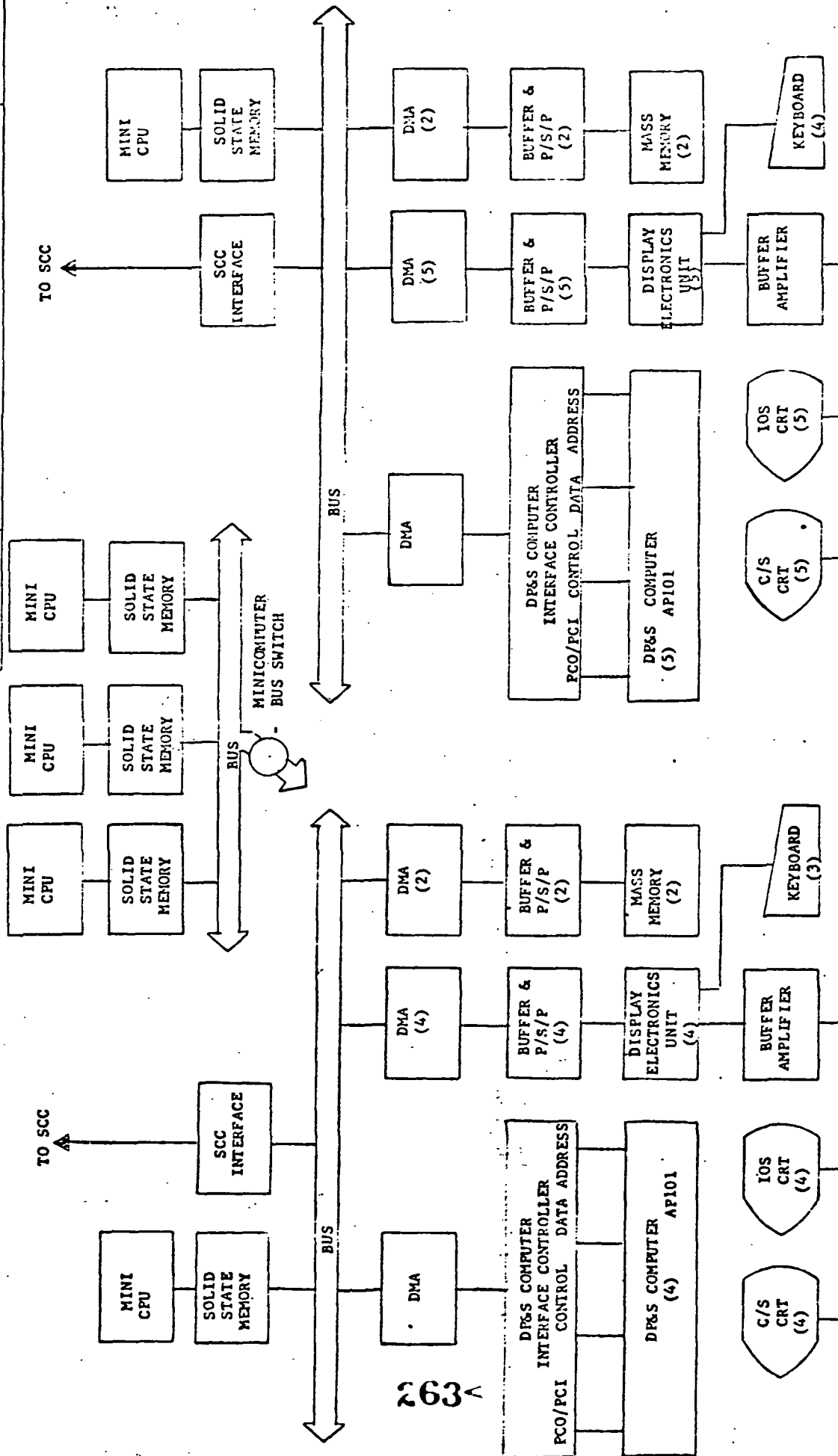
FIGURE 3.2.4-3

BLOCK DIAGRAM  
SMS OBC SYSTEM SIMULATION

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The DX11B is a programmable interface between a PDP11 Unibus and a S/360 or S/370 Multiplexer or Selector channel. In burst mode, the DX11B is capable of data transfer rates of approximately 1,000,000 halfwords per second.

The PDP11/45 interface with each IEM Model AP101 computer will be a Computer Interface Controller.

The DP&S Computer Interface Controller will provide interface between the Shuttle DP&S subsystems on-board computer and the mini-computer which acts as a DP&S subsystem data processor and Master Controller (MCM).

The interfaces between the PDP11/45 and the mass memories and display electronics units are assumed to be 1 MHz serial data channels. Therefore, in addition to the DR11-B direct memory access devices, Singer will provide required Parallel/Serial data conversion equipment and signal level conversions equipment to implement these interfaces.

The IOS CRT repeaters will be of the same type as the crew station CRT devices. As a result, no additional data formatting or I/O hardware will be required for the IOS CRT data.

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#### 3.2.4.4.2 DP&S Computer Interface Controller

As shown in Figure 3.2.4-3 four controllers are to be provided in the MBCS and five controllers are to be provided with the FBCS.

Each DP&S Computer Interface Controller (CIC) will provide data transfers to and from a DP&S subsystem computer (IBM Model AP101). In addition the CIC will provide an emulation of some of the functions of the real world DP&S subsystem IOP, but without implementing Parallel Serial/Parallel data conversion operations required in the real world system. Reference Figure 3.2.4-4.

On the AP101 side, the CIC will provide for program controlled I/O and both standard and burst mode DMA transfers of instructions and data to and from the controller. It will provide capability to accept discrete signals from the AP101 Computer, provide discrete signals to the AP101, and be capable of accepting AP101 CPU issued PCO commands and PCI Monitor requests, and generate interrupts to the AP101. The CIC will operate synchronously with the AP101 at a 25 ips minor cycle rate.

On the PDP11/45 Master Controller side, the primary CIC interface device will be the Direct Memory Access Interface (DR11-B). The DR11-B is a general purpose direct memory access (DMA) interface to the Unibus. The DR11-B rather than using program controlled data transfers, operates directly to or from memory, moving data between the Unibus and the user device.

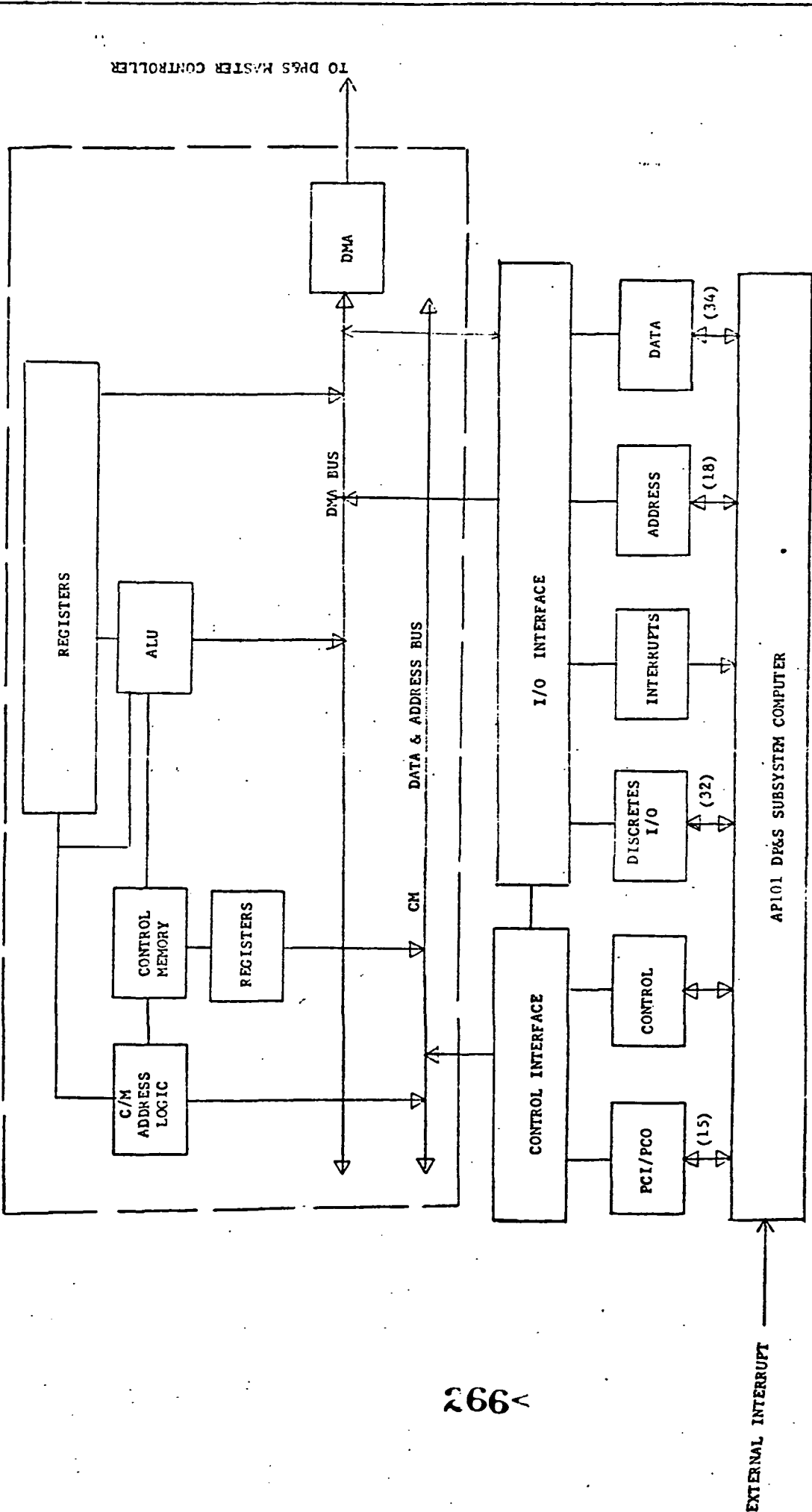


FIGURE 3.2.4-4  
DP&S SUBSYSTEM COMPUTER INTERFACE CONTROLLER



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The interface consists of four registers; command and status, word count, bus address, and data. Operation is initialized under program control by loading word count with the 2's complement of the number of transfers, specifying the initial memory or bus address where the block transfer is to begin and by loading the command/status register with function bits. The user device recognizes these function bits and responds by setting up the control inputs.

If the user device requests data from memory or a Unibus device, the DR11-B performs a Unibus data transfer (DATI) and loads its data register with the information held at the referenced bus address. The outputs of this register are available to the user device. This output data is buffered. If the user device requests data to be written into memory, the DR11-B performs a Unibus data transfer (DATD), moving data from the user to the referenced bus address. This input data from the user is not buffered. Transfers normally continue at a user defined rate until the specified number of words are transferred.

The user is given a number of control lines allowing flexible operation. Burst mode, read-modify-restore operations, and byte addressings are possible with the control structure.

Between the DR11-B and the CIC, Singer will also provide any required signal level conversion, buffering and hand-shaking electronics equipment required.

Included in this category will be provision for external clock inputs and other external interrupt signals to the AP101 and to the CIC.

3.2.4.4.2.1 CIC Operational Modes

CIC operational modes will be under program control utilizing the AP101 computer memory. CIC information transmission to or from the AP101 will be initiated by the AP101 but controlled by the CIC. The CIC will operate in the following modes:

- a) AP101 Command Mode - All data transmission under control of the AP101 computer.
- b) AP101 Listen Mode - Initialized by the AP101, data transfers will be initiated by the CIC - information transmission to the AP101 will be under control of the CIC.
- c) AP101 Direct Memory Access Mode - Standard or Burst DMA I/O to a DP&S (AP101) Computer:
- d) DP&S Master Controller DMA Mode - Standard DMA I/O to the DP&S Master Controller - initiated by the Master Controller.
- e) AP101 Cross Couple Mode - Initiated by the AP101 - informs the DP&S Master Controller (via the CIC), to transmit data to another selected CIC/AP101 pair.

The CIC will be capable of accepting instructions on the data lines from the AP101 main memory and executing these instructions via a microprogrammed control store. These instructions will control the transfer of data to/from the AP101 memory to the CIC memory and the CIC to/from the DP&S Master Controller Minicomputer memory.

The real world IOP provides a multiplex capability to transmit or receive data simultaneously on up to 31 serial/MIL channels.

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The CIC, under program control, will provide a similar capability, but will not convert data to serial form. Instead, it will receive information from the AP101 as 32 bit parallel data full words, and store it in specified tables for retransmission to the DP&S Master Controller, or conversely receive 16 bit words from the DP&S Master Controller, store it in specified tables, and retransmit the data to the AP101 when commanded.

Table 3.2.4-3 is a list of PCO commands and PCI Monitor requests which the AP101 will transmit to the CIC. Table 3.2.4-4 is a list of instructions which the CIC will be capable of executing. Programs consisting of these instructions will be contained in the AP101 memory. In addition, the CIC will transmit or receive control signals and interrupts to/from the AP101. Table 3.2.4-5 is a list of these signals.

As previously mentioned, in the real world, the IOP/MIA transmits or receives command data, and status words from a large number of external devices via 1 MHZ serial data channels. Each command data, or status word is 28 bits in length and has a format as shown in Table 3.2.4-6.

The CIC will separate and control these command data and status words and provide buffer data tables as required between the AP101 and the DP&S Master Controller Minicomputers. This will be accomplished by appropriate decoding of the address and control fields within each word received from the AP101, or in the case of data

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received from the MCM, the data will be formatted for transmission to the AP101.

#### 3.2.4.4.2.1.1 SMS Modes

The DP&S computers and associated CIC equipment will be capable of operation in any of the SMS modes including Fast Time and Slow Time. To avoid any changes to DP&S computer software, Fast Time or Slow Time will be accomplished by appropriate change to minor cycle clock interrupt to the CIC and AP101. (Reference Section 3.2.3.4). In Fast Time mode, the period of the minor cycle will be decreased to 32 milliseconds. The assumption has been made that the DP&S computers have sufficient spare computer time to allow this change, and that internal computer clocks will not be disrupted.

#### 3.2.4.4.3 Master Control Program Sequencing and Timing

PDP11/45 computer programs provided to satisfy requirements of the SMS On-Board Computer System Simulations will consist of executive programs, special purpose programs, IOB/DP&S interface programs, Main Engine Controller programs, and Main Engine Simulation programs.

The simulation programs have as their objective the simulation of the Shuttle DP&S subsystem IOP interface and in addition the

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simulation of the Main Engine Controllers and Main Engines.

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TABLE 3.2.4-3  
CPU ISSUED PCO COMMANDSReproduced from  
best available copy.Set C/M  
Program  
Counter

This command shall be used to load the C/M program counter with the contents of the displacement field. The C/M shall respond by executing the command instruction sequence commencing at the received memory address.

Halt C/M

This command shall terminate C/M instruction execution. The C/M shall enter the idle mode. The C/M program counter shall be retained for CPU monitor functions.

Load C/M  
Base  
Register

This command shall be used to load the addressed C/M base register with the contents of the displacement field. All C/M data access shall be relative to the C/M base register. This feature is intended to permit redundant data bus message inputs to different I/O map lap addresses using the same C/M program. It also permits I/O memory map changes without changing the basic C/M programs.

Disable  
MIA  
Transmitter

This command shall be used to selectively disable MIA transmitters. A bit position will be assigned to each MIA. Each bit position will be interpreted as 1 = disable, 0 = no change.

Enable MIA  
Transmitter

This command shall be used to selectively enable MIA transmitters. A bit position will be assigned to each MIA. Each bit position will be interpreted as 1 = enable, 0 = no change.

Disable MIA  
Receiver

This command shall be used to selectively disable MIA receivers. A bit position will be assigned to each MIA. Each bit position will be interpreted as 1=disable, 0 = no change.

Enable MIA  
Receiver

This command shall be used to selectively enable MIA receivers. A bit position will be assigned to each MIA. Each bit position will be interpreted as 1 = enable, 0 = no change.

Halt MIA

This command shall be used to selectively terminate MIA instruction execution. The MIA program counter shall be retained for CPU monitor functions. A bit position will be assigned to each MIA. Each bit position will be interpreted as 1 = halt, 0 = no change.

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TABLE 3.2.4-3  
CPU ISSUED PCI MONITOR REQUESTS

|                        |  |
|------------------------|--|
| Read Status<br>Bit 1   | This request shall be acknowledged by loading the designated CPU 32-bit register with status word bit 1 from each MIA and the CIC (bit 1 - MIA 1, ...bit 31 = MIA 31 and bit 32 = CIC).                                |
| Read Status<br>Bit 2   | This request shall be acknowledged by loading the designated CPU 32-bit register with status word bit 2 from each MIA (bit 1 = MIA 1, ... bit 31 = MIA 31).  |
| Read Status<br>Bit 3   | This request shall be acknowledged by loading the designated CPU 32-bit register with status word bit 3 from each MIA (bit 1 = MIA 1, ...bit 31 = MIA 31).   |
| Read Status<br>Bit 4   | This request shall be acknowledged by loading the designated CPU 32-bit register with status word bit 4 from each MIA and the CIC (bit 1 = MIA 1, ...bit 31 = MIA 31 and bit 32 = CIC).                                |
| Read CIC<br>Status     | This request shall be acknowledged by loading the designated CPU 32-bit register with CIC status word bits 1 - 14 in bit position 1 - 14 and the contents of the CIC program counter in bit positions 15 - 32.         |
| Read CIC<br>Status "A" | This request shall be acknowledged by loading the designated CPU 32-bit register with the requested CIC status word bits 1 - 14 in bit position 1 - 14 and the requested CIC program counter in bit position 15 - 32.  |
| Read CIC<br>Status "B" | This request shall be acknowledged by loading the designated CPU 32-bit register with the requested CIC status word bits 15 - 28 in bit positions 1 - 14 and the requested CIC base register in bit positions 15 - 32. |

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TABLE 3.2.4-4  
CIC INSTRUCTIONS

|                                       |  |
|---------------------------------------|--|
| Load A<br>Base Register<br>(Long)     | Load the selected CIC base register with the contents of the operand address field.  |
| Load the<br>Program Counter<br>(Long) | Load the addressed CIC program counter with the contents of the operand address field and initiate program execution if the CIC is in the command mode. This instruction shall be skipped if the CIC is not in the command mode (defined as transmitter enabled for this case).        |
| Transfer and<br>Set Return<br>(Long)  | Load the CIC program counter with the contents of the operand address field plus 2. The contents of the lower 18 bits of the operand address shall be loaded with the contents of the MSC program counter. Note the program counter was incremented by 2 after the instruction access. |
| Transfer<br>(Long)                    | Load the CIC program counter with the contents of the operand address field.   |
| Store<br>Status (Long)                | Store the contents of the CIC status word at the operand address.  |
| Load<br>Accumulator<br>(Short)        | Load CIC accumulator with the contents of the operand address (PC + displacement).   |
| Store<br>Accumulator<br>(Short)       | Store CIC accumulator at the operand address.  |
| "AND"<br>(Short)                      | Logically "AND" the contents of the CIC accumulator and the contents of the operand address. Result is placed in CIC accumulator.  |
| "XOR"<br>(Short)                      | Exclusive "OR" the contents of the CIC accumulator and the contents of the operand address. Result is placed in the CIC accumulator.   |
| Load BCE<br>Status Bit 4<br>(Short)   | Load the CIC accumulator with status word bit 4 from each MIA.   |

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TABLE 3.2.4-4 CONTINUEDInterrupt  
Computer  
(Short)

Issue interrupt to computer as specified in operand field (12 interrupts to be assigned, 1 = interrupt, 0 = do nothing). Note the intent is to notify the computer that a particular CIC instruction sequence has been completed (25/second rate data input, for example).

No-Operation  
Delay (Short)

Skip to next instruction. The intent is to permit selected CIC program instruction override by computer program insertion of this instruction with a program variable delay field for timing considerations. The LSB of the delay field is one micro-second.

Wait (Short)

The CIC halts instruction execution. CIC memory access requests will continue to be serviced.

Repeat Until  
MIA Idles  
(Short)

The CIC repeats this instruction without continuing to fetch it from memory until the selected MIA idles. It then increments the CIC program counter and continues normal instruction execution.

Transmit  
Command Word

If the MIA is in the command mode (transmitter receiver enabled), transfer lower 25 bits from the CIC instruction register to the MIA I/O register, set MIA select signal, handshake as required. If not, the instruction is skipped. The MIA address is saved in either case.

Load Base  
Register

The lower 18 bits from the CIC Instruction Register is transferred to the CIC base register.

Load Program  
Counter

The lower 18 bits from the CIC instruction register is transferred to the CIC program counter.

Transmit Data  
Words (Short)

Determine the effective memory address to fetch data from memory via CIC in DMA burst mode when serviced by CIC. Raise Want Data signal to CIC to request service. When data is provided by CIC, sequentially provide the data to the MIA I/O register for output to the subsystem. Decrement word count by two. If word count zero, access next CIC instruction; if not, repeat above.

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TABLE 3.2.4-4 CONTINUED

|                            |  |
|----------------------------|--|
| Receive Data Words (Short) | Determine the effective memory address to store data via DMA utilizing the DMA mode. Wait for words to be received sequentially by the MIA and transferred to the DCE I/O register. When 2 words have been received, request service of CIC to store data in memory. Decrement word count by two. If word count is zero access next CIC instruction, if not, repeat above.   |
| Enter Cross Couple Mode    | The operand field of this instruction shall contain the address of the MIA which is to be coupled for transmission of the data words received by this MIA. The MIA-to-MIA linkage shall be maintained until changed by Exit Cross-Couple Mode instruction or an override command. Data received while in the cross-couple mode shall be processed by the Transmitter-Receiver Data Word instruction, except for CIC memory access. |
| Exit Cross Couple Mode     | The CIC shall disengage the cross-couple linkage established by the Enter Cross-Couple Mode instruction.   |
| No Operation Delay         | The CIC executes a no-operation for the time period specified by the instruction (1 microsecond LSB).  |
| Set Time Out               | The timeout value (for the CIC to wait for the arrival of input data from an interfacing avionics subsystem following an Input command request on the bus) shall be stored in a CIC "watch-dog timer" register.  |
| Wait                       | The CIC halts instruction execution.   |
| Store Status Word          | Store the contents of the CIC status word in memory at the effective memory address.   |
| Transmit Data Long         | Same as short format instruction above in operation but with no displacement from the base register. This shall provide for large clock transfers to and from memory.)   |
| Receive Data Long          |  |

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TABLE 3.2.4-5  
CPU-MEMORY TO CIC SIGNALS

| <u>CIC</u>   |               | <u>Type</u>             | <u>Description</u>   |
|--------------|---------------|-------------------------|--|
| <u>Input</u> | <u>Output</u> |                         |  |
| X            |               | Reset All               | This signal shall be generated internally or output from the CIC. This signal when set to a logic zero shall cause all MIA transmitters and receivers to be inhibited and shall also cause the CIC to enter the idle mode. |
|              | X             | Power Interrupt         | This signal shall be issued when a power transient is detected in the CIC.   |
|              | X             | MSC IDLE                | This signal is set to a logical zero when the CIC is busy and set to a logical one when the CIC is in idle.  |
|              | X             | DMA Request             | This signal is set when a DMA is requested for input or output.  |
|              | X             | Data Ready              | This signal when set indicates to the memory that data is available for input to the memory.   |
| X            |               | Data Request            | This signal when set shall indicate that data requested for output from the memory is available.   |
|              | X             | Acknowledge IN          | This signal when set shall indicate to the memory that the CIC has acquired data from the data lines.  |
| X            |               | Acknowledge OUT         | This signal when set shall indicate to the CIC that the memory has acquired the data from the data lines.  |
| X            | X             | Other Handshake Signals | As required.   |

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|   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

|              |                   |               |
|--------------|-------------------|---------------|
| COMMAND SYNC | MIA ADDRESS FIELD | CONTROL FIELD |
|--------------|-------------------|---------------|

STANDARD MDM  
FORMAT

|               |         |               |                 |
|---------------|---------|---------------|-----------------|
| CONTROL FIELD | ADDRESS | LABEL ADDRESS | NUMBER OF WORDS |
|---------------|---------|---------------|-----------------|

MDM SEQUENCE  
FORMAT

|              |                           |                                       |
|--------------|---------------------------|---------------------------------------|
| MODE CONTROL | STARTING MDM PROM ADDRESS | NUMBER OF SEQUENTIAL INST. TO EXECUTE |
|--------------|---------------------------|---------------------------------------|

MASS MEMORY  
STD. FORMAT

|                  |         |          |                        |                             |
|------------------|---------|----------|------------------------|-----------------------------|
| M<br>O<br>D<br>E | R/<br>W | FILE NO. | STARTING BLOCK ADDRESS | NUMBER OF SEQUENTIAL BLOCKS |
|------------------|---------|----------|------------------------|-----------------------------|

MASS MEMORY  
CONTROL FORMAT

|                  |                    |
|------------------|--------------------|
| M<br>O<br>D<br>E | CONTROL FIELD TYPE |
|------------------|--------------------|

DISPLAY  
ELECTRONICS UNIT  
FORMAT

|         |   |        |         |               |                 |
|---------|---|--------|---------|---------------|-----------------|
| T/<br>R | C | K<br>B | S/<br>D | CONTROL FIELD | NUMBER OF WORDS |
|---------|---|--------|---------|---------------|-----------------|

ALL IOP LISTEN  
FORMAT

|                       |   |
|-----------------------|---|
| S<br>P<br>A<br>R<br>E | CIC PROGRAM COUNTER ADDRESS<br><br>278< |
|-----------------------|---|

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### 3.2.4.4.3.1 DP&S Master Controller Executive Program

The basic purpose of the executive program (called interchangeably, the monitor) is to cycle the various synchronous simulation programs in a specific order and at the correct time. In doing so, the monitor must be able to handle any and all interrupts associated with the real-time clock, the DP&S Interfaces and the I/O devices such as the mass memories and CRT Display Electronics Units. Additionally, during the verification and/or update phases, the monitor provides the user with error-handling routines to identify programs in error; and, timing routines to indicate program, frame and cycle times.

The cycling of the various simulation programs is determined, from a user's standpoint, by the Load Generator routine. The "load" which includes the monitor as well as the simulation programs and various data pools are brought into core via the Simulator Load routine. Therefore, most of our discussion will be with that in mind, that is, the load has been generated and loaded in the computer.

#### Control of the Simulation

The real-time simulation software for the SMS DP&S Subsystem is based upon a flexible executive program for the timed sequenced control of the trainer. The overall program layout including hardware data paths is shown in Figure 3.2.4-5.

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MC68000 DP&S INTERFACE

MAIN ENGINE (1 OF 3)

100 cps  
INTERRUPT

SCC  
TO INIT  
INTERFACE

PROGRAM-  
MABLE REAL  
TIME CLOCK

PROGRAM-  
MABLE REAL  
TIME CLOCK

EXECUTIVE  
MONITOR

MONITOR  
CONTROL

EXECUTIVE  
MONITOR

MASTER  
CONTROL  
ROUTINE

SCC  
I/O  
ROUTINE

SYSTEM  
PROGRAM  
NO. 1

SYSTEM  
PROGRAM  
NO. 2

SYSTEM  
PROGRAM  
NO. 3

SYSTEM  
PROGRAM  
NO. 1

SYSTEM  
PROGRAM  
NO. 2

SYSTEM  
PROGRAM  
NO. 3

PRIVATE  
DATA

PRIVATE  
DATA

PRIVATE  
DATA

PRIVATE  
DATA

PRIVATE  
DATA

SUBROUTINES

SUBROUTINE

SCC  
I/O  
BUFFER

SENSOR  
DATA

DR&S  
OUTPUT  
DATA

MASS  
MEMORY  
DATA

DEU  
DATA

ICC  
DATA

SCC  
I/O  
BUFFER

ENGINE  
CONTROLLER  
DATA

ENGINE  
DATA

ENGINE  
OUTPUT  
DATA

IOB/DP&S  
NO. 1  
INTERFACE

IOB/DP&S  
NO. 2  
INTERFACE

IOB/DP&S  
NO. 3  
INTERFACE

IOB/DP&S  
NO. 4  
INTERFACE

DEU  
CRT  
UNITS

MASS  
MEMORY  
UNITS

FIGURE 3.2.4-5  
DP&S INTERFACE  
PROGRAM LAYOUT

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|               |  |                   |
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One of the first things to be considered in designing the On-Line Executive Program is the sequencing of the programs which must be executed. The Simulator requires tasks to be executed in each of the following categories:

- I. Synchronous-High Rate-Time Critical (25/sec, 20/sec, and 10/sec programs)
- II. Synchronous-Low Rate-Time Critical (Programs for which the sequencing is critical or for which the time period between executions is critical)
- III. Asynchronous-Fast Response Programs (Those programs which must respond very quickly to a cue, for example, the disk interrupt routine must respond quickly to a hardware interrupt requesting disk service.)
- IV. Asynchronous-Low Priority Programs (Those programs which may be executed only when time permits)

The PDP11/45 CPU hardware and hardware interfaces are designed for multiple priority level operation. The CPU priority level can be set to any level between 0 and 7. There are seven (7) software programmable interrupt levels and 4 hardware interrupt levels. (Levels 4, 5, 6 & 7) The CPU when set at priority level 0 will allow all software interrupts and all hardware interrupts to occur. For example, if the CPU is set at level 3, it will allow software interrupts at level 4 to 7 and all hardware interrupts to occur. If the CPU were set at level 5 it would allow software

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interrupts 6-7 to occur and hardware interrupts 6 & 7 to occur. For a more detailed explanation reference should be made to the PDP11/45 Processor Handbook.

The executive is based on a time frame reference cycle of 1.0 seconds. This reference cycle will be referred to as the major cycle. During this period all of the real-time programs will have been serviced at least once. To accommodate the need for high iteration rate for the associated input/output, the time frame for the minor cycle is 40 milliseconds.

In addition, each minor cycle will be divided into four phases of 10 millisecond duration. This will allow synchronization of the DP&S Minicomputers with the Host computer at its operating minor cycle time of 50 milliseconds.

To accomplish this internal timing, each PDP11/45 will be provided with a Programmable Real Time Clock (KW11-P).

The KW11-P provides programmed real time interval interrupts and interval counting in several modes of operation. Its major features are a 16-bit synchronous binary counter, a 16-bit data buffer, a 9-bit control register, four program selectable count rates, including a crystal controlled rates of 100KHZ and 10KHZ, line frequency and one external clock input with a Schmitt trigger input.



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The interface between the host and minicomputers will occur at 40 millisecond intervals.

During the minor cycle time the DP&S interface routines will be exercised in their entirety. In addition, during this period other routines must be serviced. The particular minor cycle in which a routine will be called is a function of both the repetition rate and the loading that each routine will place on the time available. By proper choice of the minor cycle into which each of the various routines are placed, the time-loading will be spread evenly throughout the major cycle. The method used to call the routine is a Jump to Subroutine (JSR) using the stack processor. This instruction permits rapid calling of the routine and permits the stacking of calls such that as the program threads through various levels of routines, the returns are automatically stored and as each level of processing is completed the routine will exit, automatically reducing the cue length. The use of the stack processor eliminates the need of multilevel routines to maintain a safe store of the program linkage and a rapid transfer of control from one routine to another.

The executive program - in addition to handling the scheduling of the various routines -- also contains the real-time monitoring function, Power Fail/Restart, and the real-time input/output functions. The Power Fail/Restart function for the proposed device will ensure the safe shutdown of the equipment upon sensing

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of a power failure. This includes the safe-store of all volatile registers and clean up of I/O in progress (i.e., stopping disk transfer, etc.). Upon sensing a power failure, the program counter and program status registers are stored in the stack and program control is transferred to the power fail subroutine. This subroutine will safely store the volatile registers and halt the program. After power is returned to the system the routine sends out a system reset to ensure that all I/O devices are placed in the ready state. Next, the routine establishes the data paths which were terminated. At the end of this process the volatile registers are restored and the program control is returned to the interrupted routine. The program resumes execution at that point. This approach maintains the integrity of the system and permits an auto restart following return of power.

The real-time monitoring function of the executive routine provides a means of determining the average execution times of each real-time subroutine module and the worst case execution times of the programs. This is accomplished through the use of the programmable real-time clock system and the T-bit of the central processor status register. The T-bit is set at the beginning of the routine. When the jump to the routine is executed, an interrupt occurs, at which time an interrupt processor will read the real-time clock counter and store this value. The routine is then executed and at the completion the T-bit is again set, causing another interrupt. The real-time clock is then interrogated and the time difference is calculated. This time is added to the averaging values and is compared against

the worst case time to determine if the value is the worst case yet encountered or if the value can be ignored. By operator request these values may be listed to give a time history of the run times required by the subject routine or program.

The real-time input/output operation of the DP&S mini-computers is based on an interrupt-and-demand request function. This routine services the teletype, display electronics communication, mass memories, and the DP&S computer interface devices. The system works entirely through the interrupt processor asynchronously to the program. At the beginning of each 40-millisecond period the servicing of the real-time I/O is begun. At the completion of each function an interrupt is generated and the interrupt processor will initiate the next I/O function. Following the appropriate interrupts, the outputs will be serviced. At the completion of these functions the system waits for the next minor cycle to reservice the system I/O. Figure 3.2.4-6 shows the various hardware and software priority levels established. Note that the chart indicates a decreasing priority starting from the upper left hand corner to the page. Hardware devices closest to the CPU have the higher priority level. Hardware interrupt levels are BR4, BR5, BR6, and BR7 with NPR7 being the non-processor request level 7 (DMA line). PIR1 through PIR7 are the software interrupt levels and CPU0 through CPU7 represent the CPU levels.

I.H. - INTERRUPT HANDLER

DECREASING PRIORITY  
CPU PRIORITY INTERRUPT REQUEST LEVEL

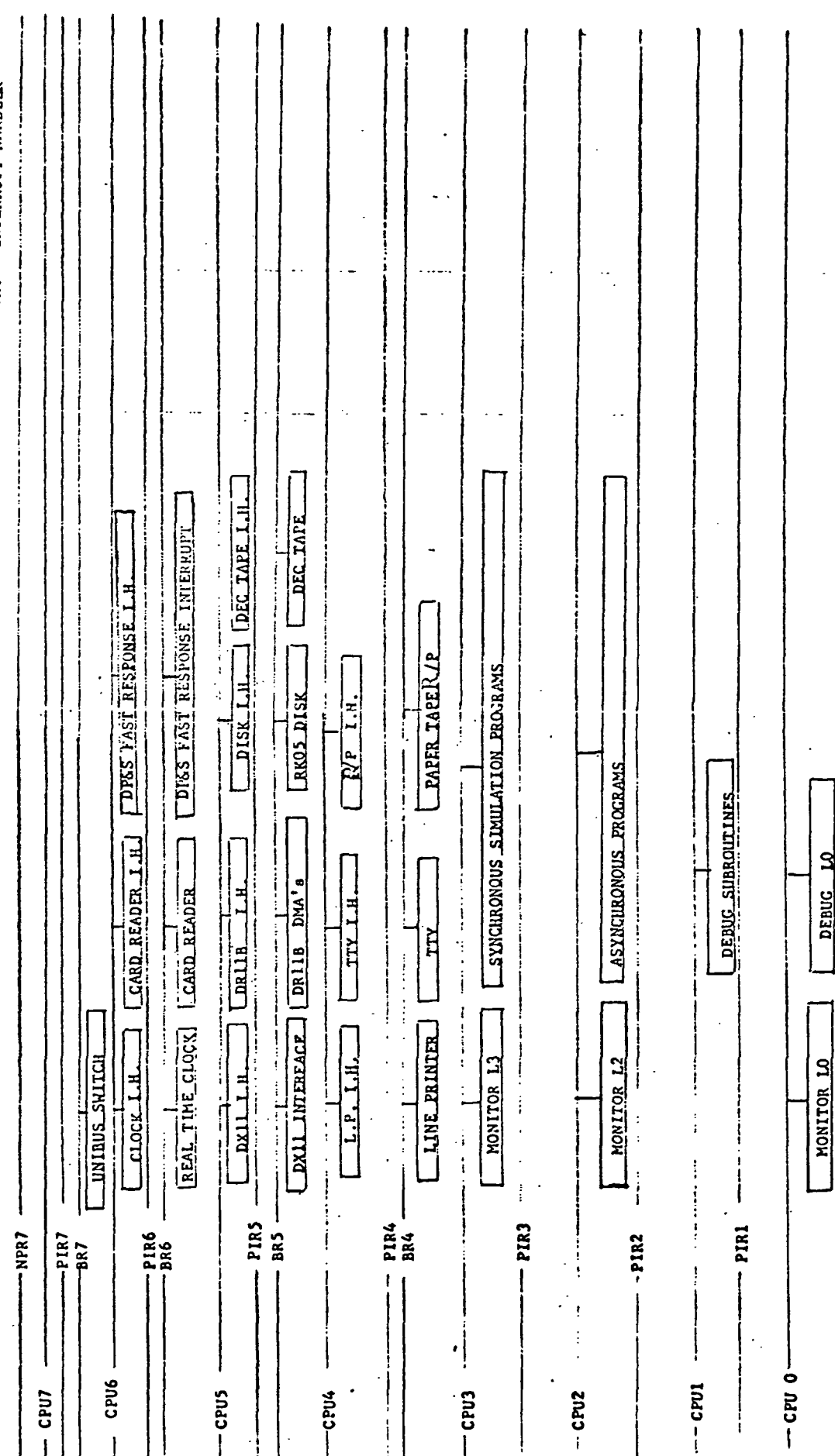


FIGURE 3.2.4-6  
FDPL1 MINICOMPUTER PRIORITY STRUCTURE

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### 3.2.4.4.3.1 Master Controller Minicomputer Memory & Time Requirements

Table 3.2.4-7 summarizes Avionics Subsystem Data Buffer requirements as extracted from the FEID Requirements Document provided by ITH.

Tables 3.2.4-8A and 3.2.4-8B summarize the I/O requirements of the MBCS Minicomputers to/from the Host computer as a function of data rates and also state average data transfers per minor cycle under the assumption that data transfers at rates lower than 20 ips may be distributed throughout the total major cycle period.

Table 3.2.4-9 summarize the I/O requirements of the Minicomputers to/from the DP&S computers.

In Table 3.2.4-10 and 3.2.4-11, the SMS Minicomputer program loadings are tabulated for the MBCS DP&S interface and the three Main Engine System Minicomputers.

TABLE 3.3.4-7  
AVIONICS SUBSYSTEM DATA  
BUFFERING REQUIREMENTS

| <u>SENSOR DATA</u>         | <u>NO. WORDS</u> | <u>FLIGHT CONTROLS</u> | <u>NO. WORDS</u> |
|----------------------------|------------------|------------------------|------------------|
| IMU                        | 54               | OMS                    | 4                |
| RADAR ALTIMETER            | 9                | RCS                    | 32               |
| STAR TRACKER               | 9                | ACS                    | 60               |
| TACAN                      | 12               | SRB                    | 8                |
| ILS                        | 18               | MPS                    | 42               |
| AIR DATA SENSORS           | 24               | ABE                    | <u>45</u>        |
| RENDEZVOUS RADAR           | 6                |                        |                  |
| RATE GYROS                 | 54               | SUBTOTAL               | 191              |
| NORM/LAT ACCEL             | 12               |                        |                  |
| DOPPLER                    | <u>12</u>        | <u>UPLINK</u>          |                  |
| SUBTOTAL                   | 210              | SGLS                   | 10               |
|                            |                  | UNIFIED S-BAND         | <u>10</u>        |
|                            |                  | SUBTOTAL               | 20               |
| <u>MANUAL CONTROLS</u>     |                  | <u>MISCELLANEOUS</u>   |                  |
| ROTATIONAL HAND CONTROL    | 36               | INTERCOMPUTER          | 1024             |
| TRANSLATIONAL HAND CONTROL | 36               | MASS MEMORY            | 512              |
| RUDDER PEDALS              | 6                | KEYBOARD               | 1                |
| SPEED BRAKE HAND CTLR      | 4                | PAYLOAD MONITOR        | 2400             |
| MASTER THRUST HAND CTLR    | 6                | DACBU                  | 780              |
| CONTROL PANEL              | 3                | GMT                    | <u>3</u>         |
| MANIPULATOR ARMS           | <u>15</u>        |                        |                  |
| SUBTOTAL                   | 106              | SUBTOTAL               | 4720             |
| TOTAL                      | 5247             | 16-BIT WORDS           |                  |

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TABLE 3.2.4-8A  
NBCS ESTIMATED WORSE CASE INPUT  
HOST TO MINICOMPUTER  
DATA RATES

| <u>DATA TYPE</u>              | <u>QTY.</u> | <u>HALFWORDS</u> | <u>INPUT RATE</u> | <u>HALFWORDS/<br/>TOTAL SEC</u> |
|-------------------------------|-------------|------------------|-------------------|---------------------------------|
| SENSOR DATA                   | 210         | 420              | 25                | 10500                           |
| MANUAL CTLS                   | 52 AN       | 104              | 25                | 2600                            |
|                               | 39 LC       | 39               | 25                | 975                             |
| FLT CTLS                      | 191         | 382              | 25                | 9550                            |
| UPLINK                        | 20          | 20               | 1                 | 20                              |
| INTERCOMPUTER                 |             |                  |                   |                                 |
| (PM)                          | 256         | 512              | 5                 | 2560                            |
| MASS MEMORY                   |             |                  |                   |                                 |
| PAYLOAD MONITOR               |             |                  |                   |                                 |
| DACBU                         | 140         | 280              | 5                 | 1400                            |
| (DISCRETES)                   | 80          | 80               | 5                 | 400                             |
|                               | 3           | 3                | 25                | 75                              |
| CONTROL                       | 20          | 20               | 25                | 500                             |
| SUBTOTALS                     |             | 968              | 25                | 24200                           |
|                               |             | 872              | 5                 | 4360                            |
|                               |             | 20               | 1                 | 20                              |
|                               |             | <u>1860</u>      |                   | <u>28580</u>                    |
| HOST TO MAIN<br>ENGINE MINI'S |             | <u>600</u>       | 25                | <u>15000</u>                    |
| TOTAL                         |             | 2460             |                   | 43580                           |

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TABLE 3.2.4-8B  
MBCS ESTIMATED WORSE CASE OUTPUT  
MINICOMPUTER TO HOST  
DATA RATES

| <u>DATA TYPE</u>              | <u>QTY.</u> | <u>HALF-<br/>WORDS</u> | <u>OUTPUT<br/>RATE</u> | <u>HALFWORDS/<br/>SECOND</u> |
|-------------------------------|-------------|------------------------|------------------------|------------------------------|
| SENSOR COMMANDS               | 76          | 152                    | 25                     | 3800                         |
| FLT COMMANDS                  | 118         | 236                    | 25                     | 5900                         |
| CREW INTERFACE                | 20          | 40                     | 5                      | 200                          |
| MANIP ARMS                    |             |                        |                        |                              |
| INTERCOMPUTER                 |             |                        |                        |                              |
| GN&C TO AUX COMP              |             |                        |                        |                              |
| MISC (TELE, ANT SEL,<br>ETC.) | 10          | 10                     | 1                      | 10                           |
| SIGNAL PROC<br>(DACBU)        | 700         | 1400                   | 1                      | 1400                         |
| DISCRETES                     | 80          | 80                     | 5                      | 400                          |
| PM                            |             |                        |                        |                              |
| PM ANNUC                      |             |                        |                        |                              |
| INPUT SENSOR DATA             | 210         | 420                    | 25                     | 10500                        |
| MAN CTLS                      | 52A         | 104                    | 25                     | 2600                         |
|                               | 39D         | 39                     | 25                     | 975                          |
| FLT CTLS                      | 191         | 382                    | 25                     | 9550                         |
| UPLINK                        | 20          | 20                     | 1                      | 20                           |
| MASS MEMORY                   |             |                        |                        |                              |
| GMT                           |             |                        |                        |                              |
| SUB TOTALS                    |             | 1333                   | 25                     | 33325                        |
|                               |             | 120                    | 5                      | 600                          |
|                               |             | 1430                   | 1                      | 1430                         |
|                               |             | <u>2883</u>            |                        | <u>35355</u>                 |
| MAIN ENGINE MINI's TO HOST    |             | 600                    | 25                     | 15000                        |
| TOTAL                         | 291         | 3483                   |                        | 50355                        |

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TABLE 3.2.4-9  
MBCS MASTER CONTROLLER/CIC/DP&S  
DATA TRANSFERS

|                   | <u>MBCS MCM TO CIC/DP&amp;S</u> |             |                         |
|-------------------|---------------------------------|-------------|-------------------------|
|                   | <u>HALFWORDS</u>                | <u>RATE</u> | <u>HALFWORDS/SECOND</u> |
|                   | 567                             | 25          | 14175                   |
|                   | -                               | 10          | -                       |
|                   | 276                             | 5           | 1380                    |
|                   | 30                              | 1           | 30                      |
|                   | <hr/>                           |             | <hr/>                   |
| TOTAL             | 873                             |             | 15585                   |
| TOTAL X 4 =       | 3492                            |             | 62340                   |
| AVERAGE PER CYCLE | 624                             |             |                         |
| AVERAGE X 4       | 2496                            |             |                         |

|                   | <u>CIC/DP&amp;S TO MBCS MCM</u> |    |       |
|-------------------|---------------------------------|----|-------|
|                   | 219                             | 25 | 5475  |
|                   | -                               | 10 | -     |
|                   | 80                              | 5  | 400   |
|                   | 400                             | 2  | 800   |
|                   | 700                             | 1  | 700   |
|                   | <hr/>                           |    | <hr/> |
| TOTAL             | 1399                            |    | 7375  |
| AVERAGE PER CYCLE | 295                             |    |       |

| PROGRAM ELEMENT         | INSTRUCTIONS | DATA | TOTAL<br>MEMORY | RATE   | LOOPING | TOTAL<br>LOOPS | MICRO<br>SECONDS<br>PER<br>LOOP | MICROSECONDS<br>PER<br>SECOND |
|-------------------------|--------------|------|-----------------|--------|---------|----------------|---------------------------------|-------------------------------|
| EXECUTIVE/MONITOR       | 6000         | 1000 | 7000            | 25     | 1       | 25             | 1000                            | 25,000                        |
| MASTER CONTROL & TIMING | 1000         | 200  | 1200            | 25     | 1       | 25             | 500                             | 12,500                        |
| IOB NO. 1,2,3,4 (BITE)  | 1000         | -    | 1000            | 25     | 4       | 100            | 1500                            | 150,000                       |
| AVIONICS SUBSYSTEM H/M  | S.R.         | 1698 |                 |        |         | 11040          |                                 | 110400                        |
| ANALOG DATA FORMAT M/H  | S.R.         | 2734 | 4500            | 20.5,1 |         | 14040          | 10.                             | 140400                        |
| AVIONICS SUBSYSTEM H/M  | S.R.         | 162  |                 | 20.5,1 |         | 1660           |                                 | 33200                         |
| DISCRETE DATA FORMAT    | S.R.         | 149  | 400             |        |         | 1220           | 20                              | 24400                         |
| (4) DEU/CRT DRIVE       | S.R.         | 1600 | 1600            | 2      | 4       | 8              | 4000                            | 32,000                        |
| (2) MASS MEMORY I/O     | S.R.         | 1100 | 1100            | 5      | 4       | 20             | 500                             | 10,000                        |
| (4) INTERCOMPUTER I/O   | S.R.         | 2100 | 2100            | 25     | 4       | 100            | 250                             | 25000                         |
| SUBROUTINE LIBRARY      | 2000         | -    | 2000            | -      | -       | -              | -                               | -                             |
| SUBTOTAL                | 10,000       |      | 20900           |        |         |                |                                 | 562,900                       |
| SPARE AT 33% OF USED    |              |      | 6967            |        |         |                |                                 | 187,446                       |
| TOTAL                   |              |      | 27867           |        |         |                |                                 | 750,3457                      |
| PROVIDED                |              |      | 32,768          |        |         |                |                                 | 1,000,000                     |

TABLE 3.2.4-10  
SMS MINICOMPUTER LOADING ESTIMATES  
MBCS DP&S COMPUTER INTERFACE



|                  |  |                     |
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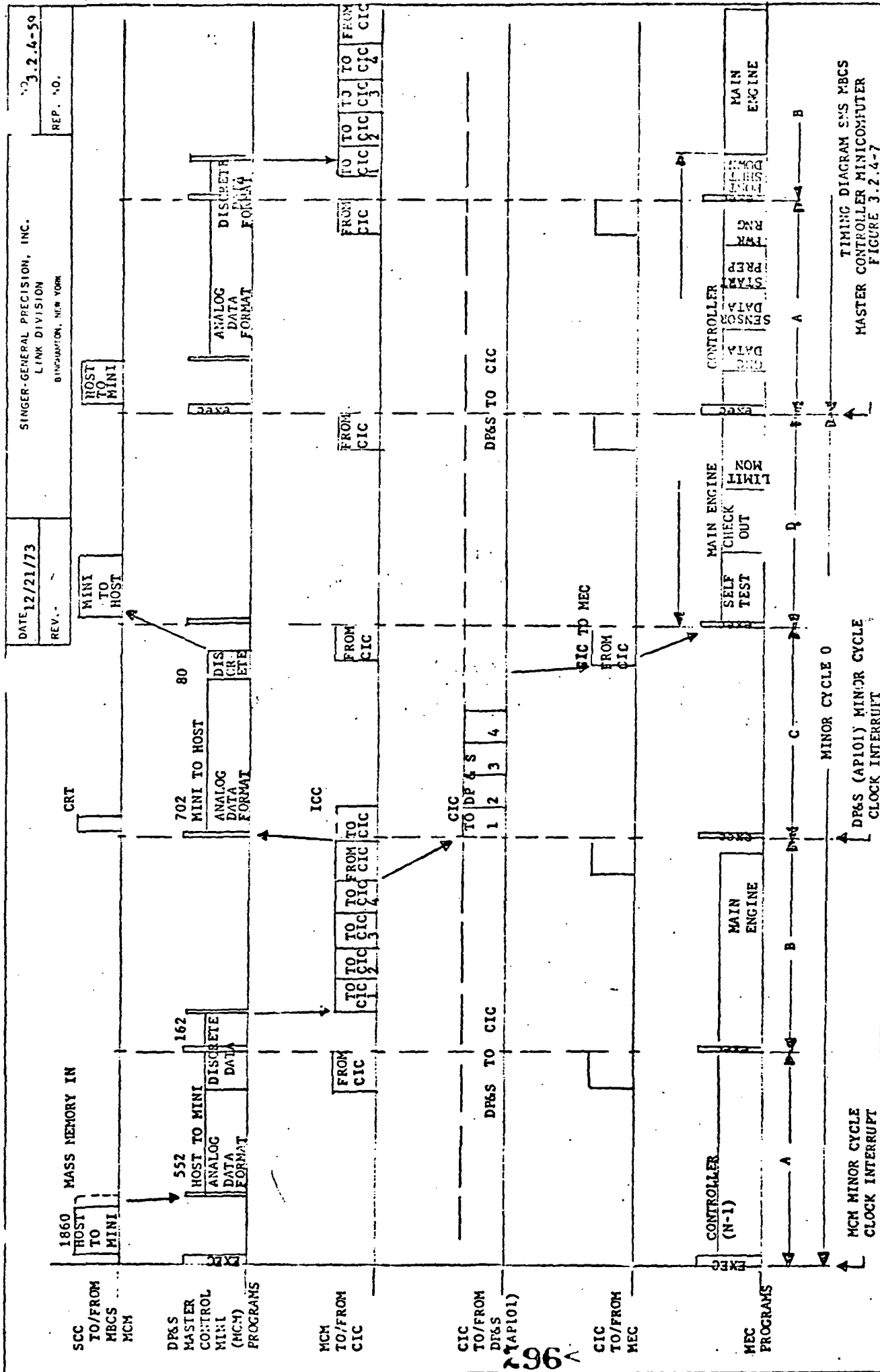
Based on these I/O and program requirements, Figure 3.2.4-7 identifies the input/output and computation activities of the five SMS DP&S Minicomputers for a period of approximately 50 milliseconds. Also shown are estimates of Unibus activity over the same period of time for the Master Controller Minicomputer, assuming a launch boost phase for the MBCS.

With reference to Figure 3.2.4-7, we can follow the operation of the MECS DP&S Interface Minicomputer through a portion of a major cycle. Initially the CPU will be in an idle state at CPU level 0. When the first clock interrupt occurs on hardware ER6 the CPU level is raised to Level 6 and certain tasks are accomplished. One of these tasks is to set software interrupt level PIR3, indicating that it is time to start execution of the Master Control Program and the high priority synchronous simulation programs.

PIR5 is also set, indicating that the SCC interface routine should be executed. The clock routine then exits by doing a return from interrupt which returns the CPU to the state which existed prior to the clock interrupt (CPU Level 0). However since PIR5 has been set the CPU immediately interrupts and raises its level to priority level 5 and the SCC interface routine is begun. The SCC interface routine consists of two parts, 1 part for each of the services required.

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The first part transfers data from the SCC to the minicomputers. The second part transfers data from the minicomputer to the SCC. The first part is scheduled to occur at the beginning of each 40 millisecond time period while the second part is scheduled to occur near the end of the same time period.

Since initialization of the Host/Mini interface hardware requires several hundred microseconds, only one transfer will be scheduled to occur in each direction per 40 millisecond period. I/O interface buffer available in each minicomputer also will be processed sequentially to minimize I/O overhead.

The SCC Interface routine sets up the first transfer from interrupt. This takes the CPU level back down to Level 0. Then PIR Level 3 is set and therefore the CPU again interrupts and goes to Level 3 and begins the executive and synchronous high priority simulation routines. Included in these are the Master Control Program and the simulation programs related to DP&S data formatting functions and IOP & DP&S computers malfunction simulation. The data format routines must be properly sequenced with relation to the data transfers to insure that current data is available for the DP&S computers. Also included in phase A are mass memory data transfers to the Master Controller Minicomputer.

After ten milliseconds, the real time clock interrupts again, indicating time to start minor cycle 0, phase B. Included in

this phase are DMA data transfers from the Master Controller Minicomputer to and from the Computer Interface Controllers.

In Phase C, Analog and Discrete Data is formatted prior to transfer from the MCM to the SCC. One of the DEU/CRT system data outputs is also processed. In Phase D, a Mini to SCC data transfer is initiated.

In Minor Cycle 1, Phase A, SCC to Minicomputer data transfers are initiated again, and the cycle is repeated. Present estimates indicate a worst case I/O transfer will require approximately 4800 halfwords to be transferred to and from the Host computer in one phase period.

In each Minor cycle, these transfers occur sequentially with transfers to or from the CIC/DP&S interface. The worst case estimate for the MCM /CIC/DP&S transfer is approximately 5000 halfwords in one phase period. Hence a worst case situation would appear to require approximately 9800 halfwords to be transferred to/from the Master Controller Minicomputer in one minor cycle. On the timing diagram the assumption has been made that each halfword transfer requires approximately one micro second of time, of which 500 nano seconds are actual bus access time. The timing diagram also implies that Unibus activity related to I/O transfers to different devices is sequenced in nature, this is in fact only partially true. When several devices are attempting data transfers, the data is interleaved on the bus as a function of device priority and transfer time and bus access



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time per device. Since each Unibus access requires approximately .500 nano seconds, approximately 5.0 milliseconds of Unibus time will be required for I/O in a worst case situation such as this.

Also to be considered is the requirement by the minicomputer to handle data from the DP&S system which requires very fast response. An example might be Main Engine commands which are tested for validity in the IOP or the Main Engine Controller, and the validity data (or error signals) retransmitted to the DP&S computers. For this type of data the minicomputer will be interrupted on a BR6 priority line when required to insure proper timing responses.

From the timing diagram, it can be seen that data transfers from the Host computer through the MCM and CIC to the DP&S computers require approximately 30 milliseconds.

Data transfers from the DP&S computers through the CIC and MCM to the SCC Host computer requires a minimum of approximately 15 milliseconds and a maximum of 40 milliseconds.

Hence total loop time, not including DP&S computation time, is 45 to 70 milliseconds.

With reference to Figure 3.2.5-14, it can be seen that there are also a number of peripheral hardware devices which can also cause interrupt, such as the Unibus switch, disk memory, card reader, paper tape reader/punch, DEC tape units, and the DEC writer terminal or teletypewriter. When the disk requires service it will interrupt the CPU and the CPU will process the disk interrupt routine at Level 5

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and return to the exec routines at level 3. In a similar manner the teletype can interrupt the CPU at level 4. Upon completion of the executive and synchronous high priority simulation routines at level 3, a flag will be set indicating that these routines have in fact been completed and a return from interrupt instruction will be executed which will return the CPU to level 0. If the teletype interrupt which is processed requested an action by the on line utilities such as fetch a location and convert it,

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and print it on the line printer, PIR1 would have been set and when CPU level was transferred back to level 0 the CPU would interrupt and execute the on line utility program at level 1. When the next clock interrupt occurs, the CPU will interrupt, transfer to level 6, and execute the clock routine again. The clock routine will check the complete flag for the priority simulation routines of the previous frame and if they were not complete, will print out an error message and continue. Again PIR3 and PIR4 would be set indicating it is time to bring the execution of the Level 3 simulation software and the DP&S output Interface Routine at level 5, and the process starts over again. If the on-line utilities of the previous frame had requested a teletype output it is possible for the level 3 simulation programs to be interrupted by the teletypewriter. Note that the teletypewriter routine is at level 4 and since the DP&S Interface is at level 5, the DP&S Interface could in fact interrupt the teletypewriter service routine. This process continues with each routine executing a return from interrupt as it is completed. By properly controlling the setting and resetting of the PIR interrupts, the CPU levels, and the return from interrupts, the software automatically keeps track of what task must be done next and at what point to return after completion of each routine. Note that this structure automatically takes care of such things as running out of time. Should the execution of the executive and synchronous priority simulation routines not be completed by the

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time the next clock interrupt is received, the CPU will interrupt, transfer to level 6 and the clock routine will check the complete flag for the last frame, since the last frame was not completed. The clock routine will cause an error message to print out and will send a flag to the level 3 executive telling it not to reset the PIR3 request upon completion of this frame. When the Level 3 routines are completed in this frame, a return from interrupt routine will be executed which will return the CPU to the state at which the CPU was at the end of the previous frame. This may be Level 2, Level 1 or Level 0. However, since the PIR3 flag was left set, the CPU will immediately interrupt again and begin the execution of the executive and synchronous priority simulation routines for the current frame. Note that the clock routine had set PIR5 so that the DP&S interface servicing was begun at the beginning of the frame regardless of the status of whether the executive and synchronous priority simulation routines were begun on time.

As with the design of any system, the design approach depends upon numerous factors. In designing the SMS Software structure a major factor to be considered is the capability to update the simulation software. After considering the capabilities of the standard DEC utility software (Assembler, Linker, Loader, etc.) it was determined that the best approach was to design the simulation software in numerous small modules or routines. These routines will be assembled and linked as stand alone modules requiring no linking, or other type

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of interface with the other simulation modules. Each module, must, however, know the location of the math subroutines, and the various data within the data pools.

These parameters are assigned to each module at assembly time by reading a common directory file from the disk which is attached to each module and assembled with that module. Should the data pools or the math libraries change in location, each routine using that data or subroutine must be reassembled with a new directory file. Using the hardware features of the PDP11/45 it is possible to assemble each routine as though it will be executed starting at memory location 0. A loader routine reads in each simulation routine in turn and locates that routine somewhere within the physical memory of the simulation computer. It is unimportant where that routine is located so long as the executive is informed of that location via a task table. Using the segmentation feature of the PDP11/45, the exec. can then cause the memory containing the specified routine to appear as though the first location is location 0.

The benefit of this design is the capability to quickly and easily update individual simulation modules without reassembly of these modules and/or the generation of new memory maps which must be distributed to each programmer, for use in debug. The fact that one module is updated in a load is completely transparent to other modules in a load, insofar as the programmer is concerned. The generation of

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the task table task to the executive by the same loader program is automatic and therefore there is no manual process involved in distributing the programs throughout the available memory.

Other considerations in the design of the software structure and the on-line executive include the different CPU modes of operation available on the PDP11/45 and the mapping of memory which includes the distribution of core memory and the layout of instruction and data memory.

The PDP11/45 has three (3) modes of operation, the Kernal mode, the Supervisor Mode, and the User Mode. The Kernal mode is intended to be the heart of the executives system. The Kernal mode allows certain restricted instructions to be executed, and by proper design of the software, numerous restrictions and/or protections can be imposed upon or provided for the supervisor and user routines.

Many of the features of the segmentation unit as described in Chapter 6 of the PDP11/45 Processor Handbook will be utilized by the On-line executive. Various segmentation registers will be utilized in the user mode to cause each user to appear as though he is being executed starting at location 0. In the supervisor mode, the supervisor mode segmentation registers will be used by the on-line utility system to allow access to the user instructions and data presently logged in at the TTY or the CRT. The Kernal mode will use the Kernal mode segmentation registers to service the hardware and to provide sequencing and protection to the various user routines.

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The memory segmentation unit also has the capability of distinguishing between instruction fetches and data accesses by separating the instructions from the data when coding the routines. It is possible to use the segmentation unit to distinguish between instruction fetches and data access thus providing a total of 64000 word addresses, 32000 of which may be used for instructions and 32000 may be used for data. All 32000 instructions may be executed and all 32000 data words may be accessed without reconfiguring memory via the segmentation registers. This is a significant advantage on large systems where the data pools are large and there is a possibility of design to execute large routines. Without this separation of instructions and data and the additional addresses provided, it would be necessary to divide the data words into a number of small blocks and the desired block to be accessed must be determined under software control.

Concurrent with the activities previously described for Minicomputer 1, the Executive/Monitors in Minicomputers 2, 3, 4 and 5 are controlling the activities of these computers.

Minicomputers 2, 3 and 4 are performing parallel simulation of the Main Engine Controllers and Main Engines during the Launch-Boost phase of the mission.

Included in each Main Engine Controller Program will be an Executive Routine Functional Element and eight additional Functional Elements as follows:

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Controller Self Test & Malfunction

Checkout

Start Preparation

Power Range Control

Post Shutdown Control

Limit Monitoring

Sensor Data Processing

GN&C Data Processing

The Main Engine Simulation Routines in the Minicomputers are primarily related to engine performance and require high iteration rates. These equations will be based upon the digital simulation prepared by the North American Rockwell Corporation.

Some of these activities such as the Engine Controller interface routines, must be scheduled to occur in each 40 millisecond minor cycle period, while others such as the Controller Self Test, Checkouts and Malfunction Simulation routines, can be scheduled for 5 per second rates.



### 3.2.5 COMPUTER COMPLEX

#### 3.2.5.1 Task Definition

The first step in the process of determining efficient candidate computer complex configurations is the definition of the tasks that must be performed. The host computer system must support a simulation task which is comprised of two simulation packages that must function simultaneously and independent of each other. The other task that the system must support is a time sharing task which is comprised of batch processing and interactive programming.

##### 3.2.5.1.1 Simulation Task

-- The Shuttle Mission Simulator (SMS) will be divided into two training stations. One of the training stations will be on a six degree of freedom motion base (MBCS), while the other training station will be on a fixed base (FBCS). The host computer system must provide the capability for simultaneous, independent training activities in both training stations. Figure 3.2.5-1 defines the configuration of SMS in a functional manner. The following paragraphs define in more detail the hardware and software requirements of the simulation task.

##### 3.2.5.1.1.1 Computational Requirements

Page 2.4-16 identifies in detail the computer loading that is required for the MBCS and FBCS. In order to maintain uniformity for all candidate computers, an instruction is equivalent in size to one computer word.

A summary of the computational requirements for the SMS is given below:

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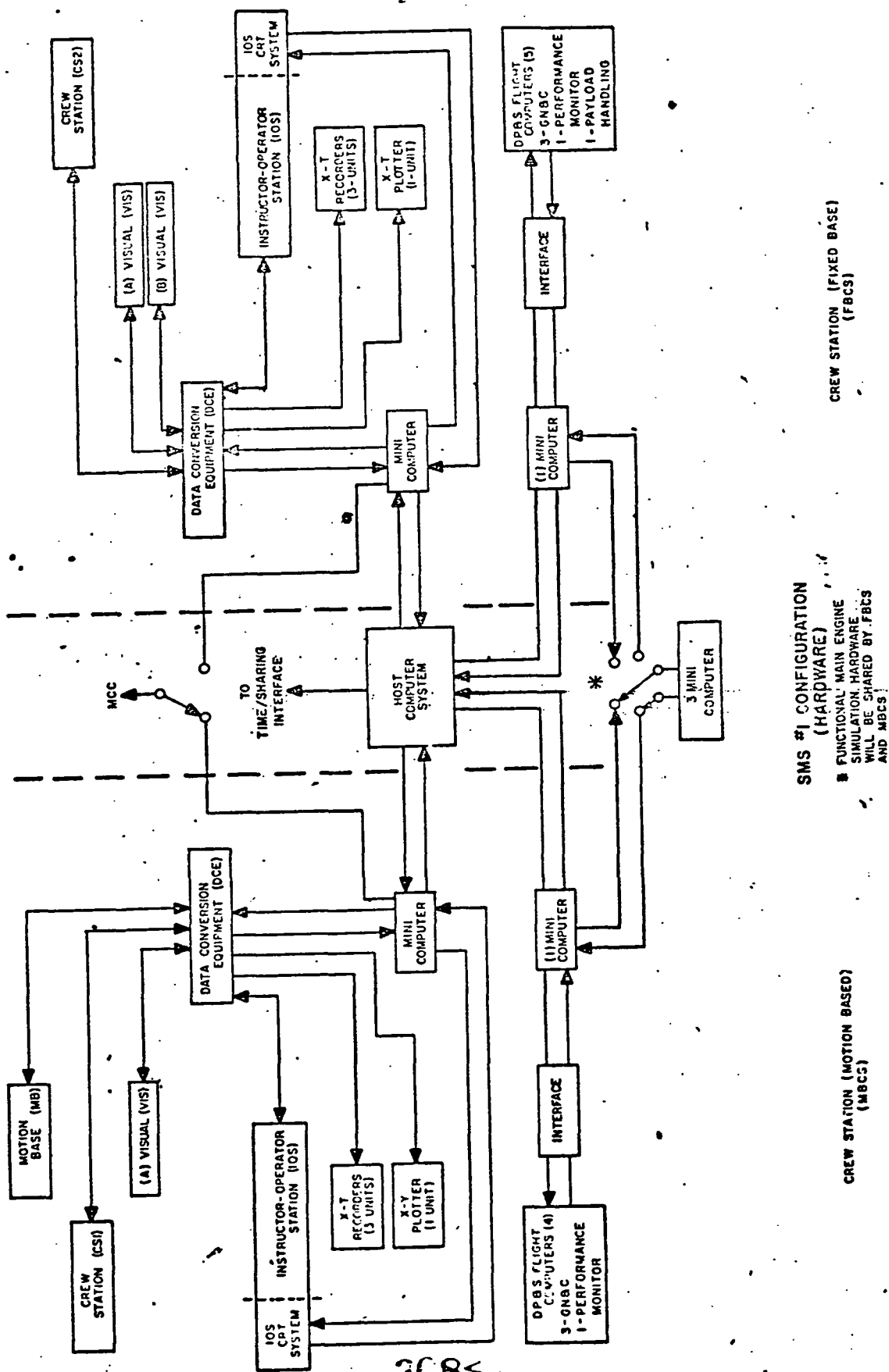
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Pages 3.2.5-3 through 3.2.5-8 deleted. See Pages 2.4-16  
through 2.4-21D for computer loadings.

| TRAINING<br>STATION | EXECUTABLE<br>INSTRUCTIONS | DATA<br>BASE | MIP |
|---------------------|----------------------------|--------------|-----|
| MBCS                | 129K                       | 108K         | 2.0 |
| FBCS                | 145K                       | 120K         | 3.3 |
| TOTAL:              | 274K                       | 228K         | 5.3 |

3.2.5.1.1.2 Input/Output Requirements

The input/output requirements for the SMS can be categorized into three major areas for each training situation:

D DATA CONVERSION EQUIPMENT (DCE)

| TRAINING<br>STATION | DEVICE         | CHANNELS | SERVICE<br>RATE |
|---------------------|----------------|----------|-----------------|
| MBCS                | Digital Input  | 2767*    | 20/sec          |
|                     | Digital Output | 3780*    | 20/sec          |
|                     | Digital/Analog | 423**    | 20/sec          |
|                     | Analog/Digital | 53**     | 20/sec          |
|                     | TOTAL:         | 7023     |                 |
| FBCS                | Digital Input  | 2915*    | 20/sec          |
|                     | Digital Output | 2777*    | 20/sec          |
|                     | Digital/Analog | 463**    | 20/sec          |
|                     | Analog/Digital | 48**     | 20/sec          |
|                     | TOTAL:         | 6203     |                 |

\* One computer halfword/DCE device channel

\*\* One computer word/DCE device channel

Data rate for Host Computer to/from DCE Mini.

## MECS

|                         |         |        |
|-------------------------|---------|--------|
| DCE                     | 149,980 | HW/sec |
| ILS CRT                 | 22,800  | HW/sec |
| Block I Trajectory Data | 3,800   | HW/sec |
| Block II FM Data        | 63,700  | HW/sec |
| Command Data            | 160     | HW/sec |
| Total                   | 240,440 |        |

## FBCS

|         |         |        |
|---------|---------|--------|
| ILS CRT | 134,200 | HW/sec |
| Total   | 164,680 |        |

o FLIGHT COMPUTER SIMULATION

Both the MECS and FBCS must support the following worst case

flight computer interfaces:

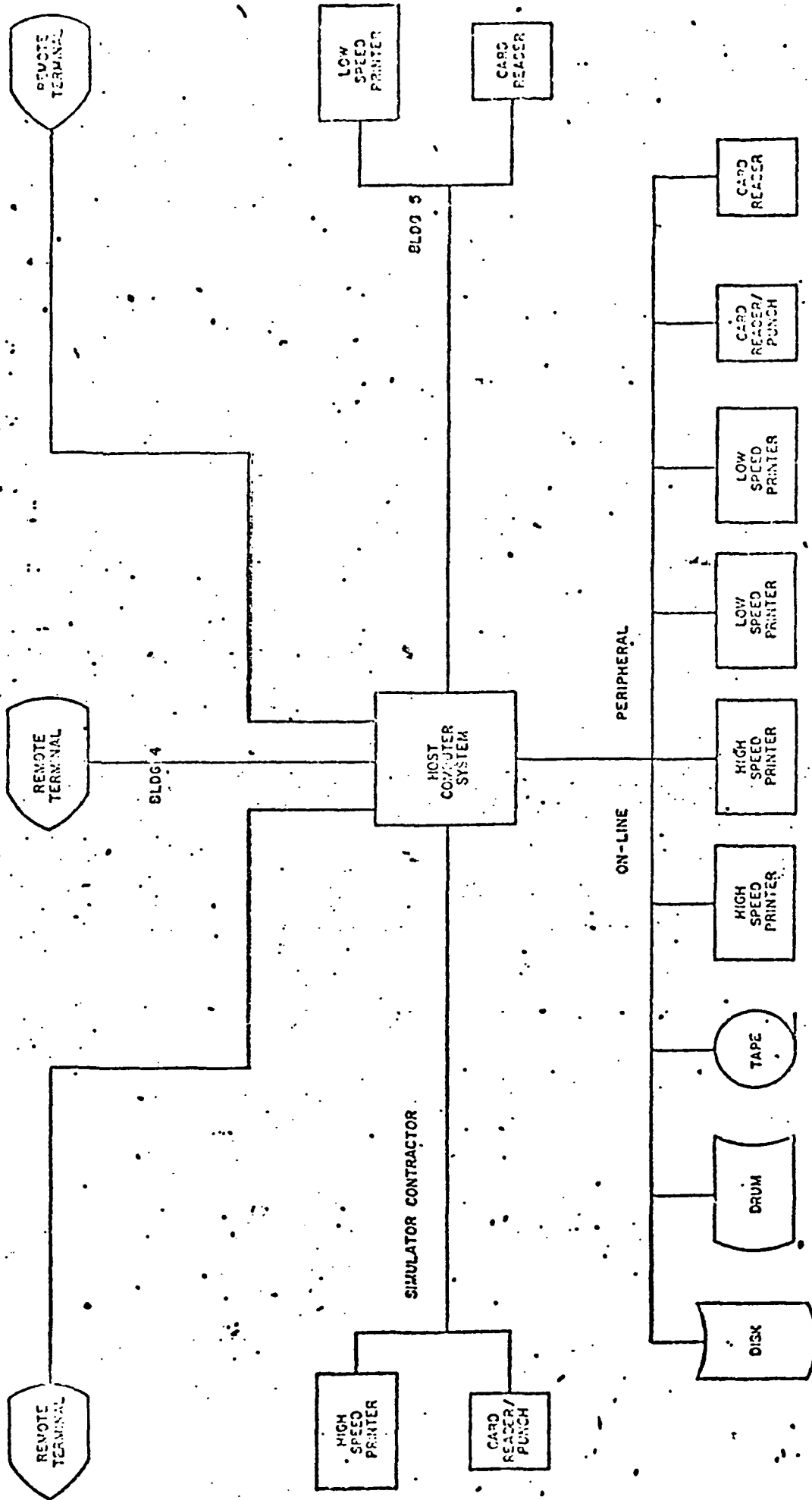
|                               | MAIN<br>ENGINE | AVIONICS<br>MECS | FBCS         |
|-------------------------------|----------------|------------------|--------------|
| Transfer rate                 | 1 MW/sec       | 1 MW/sec         | 1 MW/sec     |
| Word size                     | 16 bits        | 32 bits          | 32 bits      |
| Data rate:                    |                |                  |              |
| Input                         | 25/sec         | 25/sec           | 25/sec       |
| Output                        | 25/sec         | 25/sec           | 25/sec       |
| Data block                    | 200 words      | 1500 wds         | 1900 wds     |
| Number of computers           | 3              | 4                | 5            |
| Transfer rate (Host Computer) | 30,000 wd/sec  | 61905 wd/sec     | 75885 wd/sec |

3.2.5.1.2 Time-Sharing Task

The host computer system must provide the capability to support local/remote batch processing and interactive programming in a multiprogramming or multiprocessing mode. Figure 3.2.5-2 defines the functional time-sharing and on-line peripheral requirements that the host computer system must support.

3.2.5.1.2.1 Facilities

o Batch Stations



TIME SHARING CONFIGURATION

- Simulator Contractor (Off-Site)

- Line Printer

- Card Reader

- Building 5 (On-Site)

- Line Printer

- Card Reader

- Interactive Terminals

A total of 6 terminals will be required. Two terminals will be located at Building 5, Building 4 and the simulator contractor's off-site location. The terminals will not necessarily be located in the immediate area of the Batch Station.

### 3.2.5.1.2.2 Capabilities

- Throughput

- Local/remote batch: 600 jobs/24 hours
  - Interactive terminals: 60% utilization

- Job Types (typical)

- Compiles (FORTRAN - 75%, COBOL - 15%)\*
  - Assemblies (10%)\*
  - Compile, Load, Go
  - File Management

\*500 to 1,000 statements per compilation or assembly.

- Data Reduction
- Data Management System
- Load Module (one or more programs) Creation and Checkout
- o Language Processors (minimum)
  - Conversational FORTRAN
  - Conversational COBOL
  - Conversational Assembler
  - Data Management System (CODASYL Standard)
  - Conversational Debug Package
  - User Generated
- o Job Initiation
  - Local/remote batch station
  - Interactive Terminal
- o MIP Requirements - 0.7



3.2.5.2 Computer Complex Requirements

The requirements specified in the following paragraphs will provide a computer complex configuration which may be used in an efficient and flexible manner.

3.2.5.2.1 Host Computer System

|                    |             |                    |
|--------------------|-------------|--------------------|
| • <u>MIP Rate-</u> | 5.35        | (Simulation)       |
|                    | <u>1.33</u> | (Spare)            |
|                    | 6.68        | (Simulation Total) |
|                    | .50         | (Operating System) |
|                    | <u>.70</u>  | (Time Sharing)     |
| TOTAL              | 7.88        | (Capacity)         |

• Word Size - 32 Bit (minimum)

| - <u>Floating Point</u> | <u>Sign</u>        | <u>Exponent</u> | <u>Fraction</u> |
|-------------------------|--------------------|-----------------|-----------------|
| Single Precision        | 1 Bit              | 7 Bits          | 24              |
| Double Precision        | 1 Bit              | 7 Bits          | 48              |
| - <u>Fixed Point</u>    |                    |                 |                 |
| Single Precision        | Sign Bit + 31 Bits |                 |                 |
| Double Precision        | Sign Bit + 59 Bits |                 |                 |

• Registers - 16 (general)• Addressable Core Storage (minimum)

|          | <u>Instructions</u> | <u>Data Base</u> |
|----------|---------------------|------------------|
| MBCS     | 129K                | 108K             |
| FBCS     | <u>145K</u>         | <u>120K</u>      |
| SUBTOTAL | 274K                | 228K             |
|          | <u>228K</u>         |                  |
|          | 502K                | (Allocated)      |
|          | <u>126K</u>         | (Spare)          |
| TOTAL    | 628K                | (Capacity)       |

● Instruction Set Class

Load/Store

Binary

Decimal

Floating Point

Fixed Point

Logical

Test/Branch

Search/Compare

Shift

Index

Byte/String Manipulation

Supervisory

● Input/Output Channels

|      | <u>Number</u> | <u>Data Rate</u> |
|------|---------------|------------------|
| MBCS | 2             | 200K Words/Sec   |
| FBCS | 2             | 200K Words/Sec   |

3.2.5.2.2 Time-Sharing Requirements3.2.5.2.2.1 Batch Stations● Simulator Contractor (Off-Site)

- 1 Line Printer: 1000 LPM (minimum)
- 1 Card Reader: 1200 CPM

• Building 5 (On-Site)

- 1 Line Printer: 600 LPM .
- 1 Card Reader: 250 CPM

• Baud Rates

- 9.6K Baud (minimum)
- 19.6K Baud (Satisfactory)
- 40.8K Baud (Simulator Contractor Only)

3.2.5.2.2.2 Interactive Terminals

## • At each Site:

2 Alphanumeric

- 1000 displayable characters/terminal
- Response rate - 1-3 secs
- 1 keyboard/terminal
- 1 Hardcopy unit/terminal
- Baud rate - 2400 (minimum)

3.2.5.2.3 On-Line Peripheral Requirements

The on-line peripheral identified in the following paragraphs should be accessible by each CPU in the host computer system.

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### 3.2.5.2.3.1 Rotating Mass Storage

- Disc

- Capacity: 1.7 billion characters
- Access Time: 30 M.S. (ave.)

### 3.2.5.2.3.2 Magnetic Tape

- 4 - 800/1600 BPI 9 track
- 2 - 200/556/800 BPI 7 track

### 3.2.5.2.3.3 Line Printer

- 2 - 1200 LPM (minimum)
- 2 - 600 LPM (minimum)

### 3.2.5.2.3.4. Card Reader/Punch

- 2 - 1000 Read/250 Punch

### 3.2.5.2.3.5 Input/Output Channels

• Channels should be provided which will accommodate all peripheral equipment with minimum practical channel contention by the CPU(s) for all the peripheral. The minimum that shall be provided is:

| <u>Number</u> | <u>Data Rate</u>    |
|---------------|---------------------|
| 2             | 200K Words/Sec      |
| 1             | 20K words/sec (MPX) |

### 3.2.5.2.3.6 Spare

- MIP: - 25% (Minimum)
- 25% spare should be available for all other computer complex resources.

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#### 3.2.5.2.4 Operating System (OS)

##### 3.2.5.2.4.1 Overhead

Based upon the requirements that have been identified in the previous sections, the maximum (worst case) overhead for the OS should be as follows:

Core - 75K words

Time - 0.5 MIP

##### 3.2.5.2.4.2 General Capabilities

In general, the Operating System (OS) of the Host Computer must provide a hospitable environment for the proposed real-time simulation software and must contain certain intrinsic capabilities as follows:

- Capability for executing a mix of programs including batch, interactive, and real-time programs in multiprogramming or multiprocessing mode.
- Provide a user-accessible internal clock for synchronizing and timing events.
- Provide a capability for exploiting the inherent parallelism of real-world events reflected in simulation processes by permitting the initiation and termination (synchronization) of independent, asynchronous program execution sequences.
- Provide the ability to create and execute re-entrant code sequence.
- Provide a comprehensive interrupt structure with optional user handling of interrupts.
- Accommodate non-pollled communications (digital) input, both synchronous and asynchronous, at varying speeds and employing a variety of code formats and line disciplines.

It is recognized that these capabilities (as well as features described below) are made available by hardware or software (or both), depending on the architecture of the machine. Therefore, a functional description will be utilized unless a feature is clearly identifiable as hardware or software.

#### 3.2.5.2.4.3 OS/Simulation Software Interface

The general relationship between the OS of the host machine and the required simulation software merits close examination as it can have a significant impact on the magnitude of the overall software programming task. Ideally, the host OS would provide all needed functions, thereby reducing the programming task to simulation software exclusively. In a worst case situation, there would be no host OS at all suitable as environment for the simulation software (in which case an OS would have to be developed in addition to the simulation software). The 'division of labor' between the OS and the simulation software must be carefully identified in order to correctly assess the relative merits of candidate OS's.

#### 3.2.5.2.4.4 System Synchrony

In any large time-dependent system there must exist a means of achieving global synchrony of asynchronous events. This clearly involves several aspects:

- A user accessible real-time clock of suitable resolution.
- Ability of user programs to establish and receive time interrupts.
- Ability to initiate and synchronize asynchronous execution of multiple program modules.
- Ability to establish and alter execution priorities of program modules.

- Ability of the OS to establish and honor priorities for various execution modes (batch, interactive, and real-time).

- Ability to handle non-pollled input arriving at arbitrary intervals without data loss.

#### 3.2.5.2.4.5 Global and Common Reference

The host software must provide a capability for the declaration and use of external (or global) references or names accessible to any referencing program module. In a like manner, it must provide the ability for program modules to share common data, e.g. 'named common' feature of FORTRAN. The realization of these features must be provided in the Link Edit or Collection phase discussed below.

#### 3.2.5.2.4.6 Link Edit or Collection

The host software must allow the linking or collection of discrete software segments into executable modules. It must allow collection of object code resulting from different processors, e.g., FORTRAN and Assembler.

#### 3.2.5.2.4.7 Interrupt Structure

The host machine must incorporate multi-level interrupts (internal, external, fault, etc.) as required in any multi-programmed environment. Additionally, the interrupt structure must include time-dependent (clocked) interrupts which can pass control from the OS to user programs. In general, the interrupt structure must allow optional user handling of interrupt contingencies and must also afford the user the option of not relinquishing control on the initiation of the I/O requests, if he so desires.

#### 3.2.5.2.4.8 Program Residency/Non-Residency

In the event that the host machine cannot accommodate the entire simulation software as resident or simultaneously present, provision must be included for execution of non-resident elements through an overlay or paging mechanism (or the equivalent thereof). It is extremely important that this mechanism not compromise the basic time dependency and control outlined elsewhere on which the entire simulation program is postulated.

#### 3.2.5.2.4.9 Language Processors

The host OS must contain language processors capable of processing user-supplied source language statements. In particular, a FORTRAN or higher level language processor must be supplied. For those needed computational functions not present in FORTRAN, an Assembler must also be provided and it must be possible to enter Assembler from FORTRAN and vice-versa. The FORTRAN processor must conform to current ANSI standards for the FORTRAN language. It must also be possible to link edit (collect) elements of FORTRAN and Assembler into a single program.

#### 3.2.5.2.5.10 Libraries

The OS should provide at a minimum the following libraries:

- System Utility
- Mathematical
- Macro

#### 3.2.5.2.5.11 Computer System Accounting

A statistics gathering system must be provided which will have the capability of accounting for the utilization of all computer system resources.



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3.2.5.3 Candidate Computer Configurations.

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### 3.2.5.3.1 Control Data Computer System

The CDC Computer System is comprised of one Cyber 70 Model 76 and one Cyber 70 Model 73. The Model 76 provides the capability to support the simulation task, while the Model 73 provides the capability to support the time sharing task. The two Cybers are interfaced together for the following reasons:

- The Model 73 will use the standard 6000 SCOPE 3.4 Operating System as a base and perform the following tasks in support of the SCOPE 2 Operating System in the Model 76. See Figure 3.2.5-3.

- Unit Record Interface

It will be the interface between local unit record equipment such as card readers, line printers, punches, etc., and the Model 76 CPU.

- Communications Interface

It will be the interface between communication lines and the 7600 CPU. The communications interface will permit Remote Batch capabilities on the 7600 System.

- Model 73 Operator Station

The Model 73 can serve as either a normal station or the operator station having the ability to control the execution of all jobs in the Model 76.

- Permanent File Handling

The Model 76 will be provided ATTACH and CATALOG features of Model 73 permanent files.

#### 3.2.5.3.1.1 Host Computer

- Model 76

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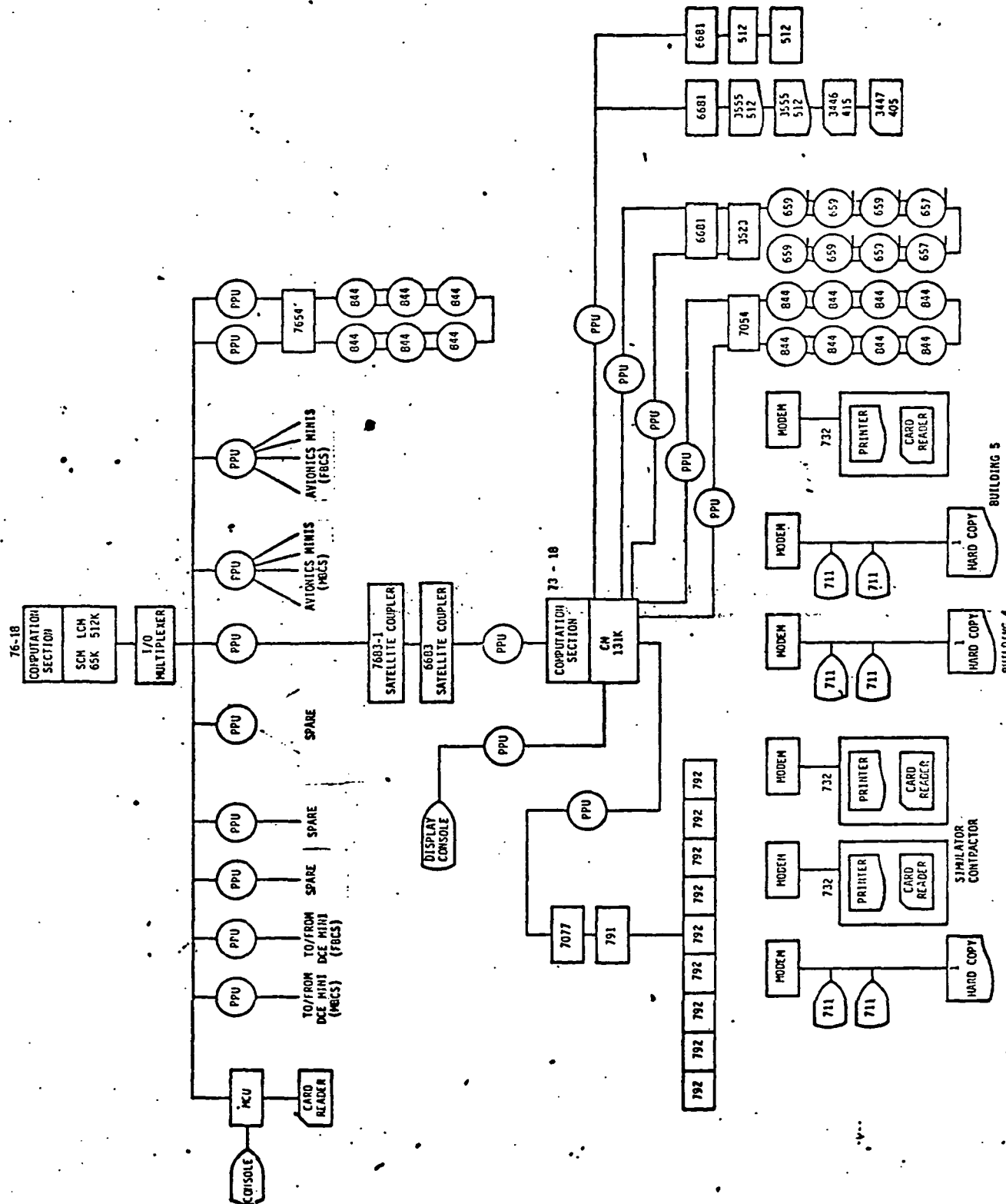
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CDC CYBER 70 MOD 73, 76 COMPUTER SYSTEM

FIGURE 3.2.5-3

- 15.0 MIP rate
- 60-bit internal word
- Binary computation in fixed point and floating point format.
- Nine independent functional units.
- 12-word instruction stack.
- Synchronous internal logic with 27.5 nanosecond clock period.
- Operating registers
  - Eight 60-bit operand registers (X registers)
  - Eight 18-bit address registers (A registers)
  - Eight 18-bit index registers (B registers)
- Precision
  - Fixed point range  $\pm 2^{47} - 1$
  - Floating point range (magnitude)  $10^{322}$  to  $10^{-293}$
  - Double precision capability
- Instruction set class
  - Arithmetic: Load/store
  - Binary
  - Floating point
  - Fixed point
  - Logical
  - Test/Branch
  - Search/Compare
  - Shift
  - Index
  - Population count
  - Supervisory

## • Small Core Memory

- 32,768 or 65,536 60-bit words of coincident current memory with five parity bits per 60-bit word.
- Organized into 16 or 32 independent banks (2,048 words per bank).
- 275 nanosecond read/write/cycle time.
- 27.5 nanosecond per word maximum transfer rate.

## • Large Core Memory

- 256,000 or 512,000 60-bit words of linear select memory with four parity bits per 60-bit word.
- Organized into four or eight independent banks (64,000 words per bank).
- 1,760 nanosecond read/write/cycle time.
- Eight words read simultaneously each reference.
- 27.5 nanosecond per word maximum transfer rate (512,000 memory only).

## • I/O Multiplexer

- Seven, eleven, or fifteen independent 12-bit channels.
- Each channel bi-directional.
- Fixed SCM buffer areas for each channel; 128 or 256 60-bit words.
- Normal channels and high speed channels.

Normal ChannelHigh Speed Channel

Input: 60 clock periods/60-bit word 34 clock periods/60-bit

Output: 72 clock periods/60-bit word 35 clock periods/60-bit

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## ● Peripheral Processor Unit Characteristics

## - Computation Section

12-bit internal word

Binary computation in fixed-point

Synchronous internal logic with 27.5 nanosecond clock period

## - Operating Registers

18-bit Arithmetic Register (A)

12-bit Program Address Register (P)

13-bit Memory Read Register (X)

12-bit Instruction Register (fd)

12-bit Working Register (Q)

## - Core Memory

4,096 12-bit words of coincident current memory with a  
parity bit for each 12-bit word (odd parity)

Organized into two independent banks (2,048 words per bank).

275 nanosecond read/write cycle time

## - Input/Output Section

Up to 15 independent channels (asynchronous)

Each channel bi-directional (12-bit)

## ● Maintenance Control Unit

- Used to dead start system

- Performs basic recovery

- Directs and monitors system maintenance

- Own card reader

- Own visual display

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3.2.5.3.1.2 Time Sharing

The time sharing system operated in the Cyber 70 Model 73 computer.

## • Central Processor

- 60-bit word length.
- Computation in Floating Point and Fixed Point, Single and Double Precision.

- Memory transfer rate of up to one word each 100 nsec.
- 60-bit instruction Buffer register.
- Memory protect
- 8 18-bit address registers
- 8 18-bit increment registers
- 8 60-bit operand registers

## • Peripheral and Control Processor

- 12-bit word length
- Computation in Fixed Point arithmetic.
- Time-shared access to Central Memory.
- Internal memory of 4,096 12-bit words.

## • Central Memory

- Capacities of 16,384, or 32,768, or 49,152, or 65,536 or 98,304, or 131,072 60-bit words.
- Independent bank construction, to allow separate overlapped access to each 4K bank.
- Transfer rate of up to one word each 100 nsec in phased operation.

## • 711-1 CRT Display Terminal

- 16 lines of 80 characters
- 10 X 8 inch viewing area
- Standard typewriter keyboard
- 64 alphanumeric and symbols plus control codes.
- RS232-C interface designed for synchronous data transmission to 4800 BPS, half duplex.

- Cursor control:

- Up

- Down

- Left

- Right

- Home

- Inverse Video

- 5 X 9 dot matrix using 525 line TV raster

- 60 HZ refresh rate

- Character size: .25 X .125 inch

- o 732-10 Medium Speed Batch Terminal

- 8K 8-bit bytes of 16-bit 1.1  $\mu$ s memory

- 500 CPM reader

- 600 LPM, 136 column printer

- Operator keyboard

- Designed to RS232C or CCITT V24 specifications

- Speed range from 2000 to 9600 BPS

- o 791-1 Communication Subsystem

- Provides interface to 7077-1 or 7611-10 service station

- Fan out logic for up to 48 communication adapters



- Communication interface for up to 16 792 adapters
- 4096 16-bit core memory with 200  $\mu$ s cycle time

- 792-1 Communications Adapter

- Performs input synchronization
- Full duplex character assembly/disassembly
- EIA RS232-C interface
- Compatible with bell 201 and 203 data sets
- May provide CCITT compatibility
- Will operate at 2400, 4800 or 9600 BPS

- 7077-1 Communications Station

- Controls up to three 791-1 controllers
- Provides 8K words memory with 1.1  $\mu$ s cycle time
- Requires one dedicated PPU

### 3.2.5.3.1.3 On-Line Peripheral

- 3528-3 Magnetic Tape Controller

- Two channel connection
- Controls up to 8 Model 657 or 659 (intermixed) tape units
- Provides code conversion
- 200, 556, and 800 BPI NRZI recording
- 1600 BPI phase encoded

- 405 Card Reader
  - 1200 CPM (80 column cards)
  - 4000 card hopper capacity
  - 4000 card stacker
  - 240 card secondary stacker
- 415 Card Punch
  - Punch 250 CPM
  - Programmable offset stacker
  - 1208 card hopper
  - 1500 card stacker
  - Read check after punch
- 512-1 Line Printer
  - Prints 1200 LMP (48 character set)
  - Skips 70 inches/sec at 6 lines/inch
  - Skips 60 inches/sec at 8 lines/inch
  - Prints 136 columns
- 657-4 Magnetic Tape Transport
  - 7 track
  - 30K and 120K 6-bit C/S
  - 200, 556, 800 BPI NRZI recording
  - Read/write 150 IPS
  - Forward/Reverse read
- 659-4 Magnetic Tape Transport
  - 9 track
  - 90 and 180K 8-bit C/S
  - 800 BPI NRZI recording

- 1600 BPI phase encoded recording
- Read/write 150 IPS
- Forward/reverse read
- 844-2 Disk Storage Unit
  - Maximum capacity 869 million bits (unsectored format, 404 tracks)
  - 10-55 ms positioning time (30 ms average)
  - 618 million bits/sec transfer rate

#### 3.2.5.3.1.4 Operating System (OS)

##### 3.2.5.3.1.4.1 Overhead

- Cyber 73 (Scope 3.4)
  - Core: 16K
  - MIP: .0115
- Cyber 76 (Scope 2)
  - Core: 65K
  - MIP: .5

##### 3.2.5.3.1.4.2 General Capabilities

- Provides the execution of a mixture of batch, interactive and real-time programs in a multiprogramming and multiprocessing mode.
- User is provided access to the system clock.
- The central processor initiates the I/O request. The PPU performs the requested I/O function while the central processor continues other work. At the end of the I/O function, the PPU will signal the central processor. The central processor can then determine whether or not to initialize any new procedures.

- The interrupt sequences are normally re-entrant
- The interrupt structure is established by the hierarchy of I/O channels and system functions.
- Intelligent processors on remote interfaces can respond to various types of communications.

#### 3.2.5.3.1.4.3 C/S Simulation Software Interface

There are structurally four parts to the central system, as shown in Figure 3.2.5-4. These are: the job supervisor, the interrupt handlers, the system executive, and the system interchange.

- System Interchange

The system interchange coordinates system operations by transferring control to the other parts of the system and assigning the CPU.

- Interrupt Handlers

The interrupt handlers service hardware/software interrupt functions. These functions include: the transfer I/O data between LCM buffers and the CPU channels via the hardware SCM buffers, the processing of clock interrupts, and the processing of software generated interrupts.

- System Executive

The system executive consists of overlays that perform system functions of resource allocations, scheduling, I/O request queue management, and some job management.

- Job Supervisor

The job supervisor performs functions specifically oriented to a single user job which include user level (or logical) I/O management, the reconciliation of logical and physical data structures, and file management. The job supervisor also performs tasks associated with the management

## JOB ORIENTED FUNCTIONS

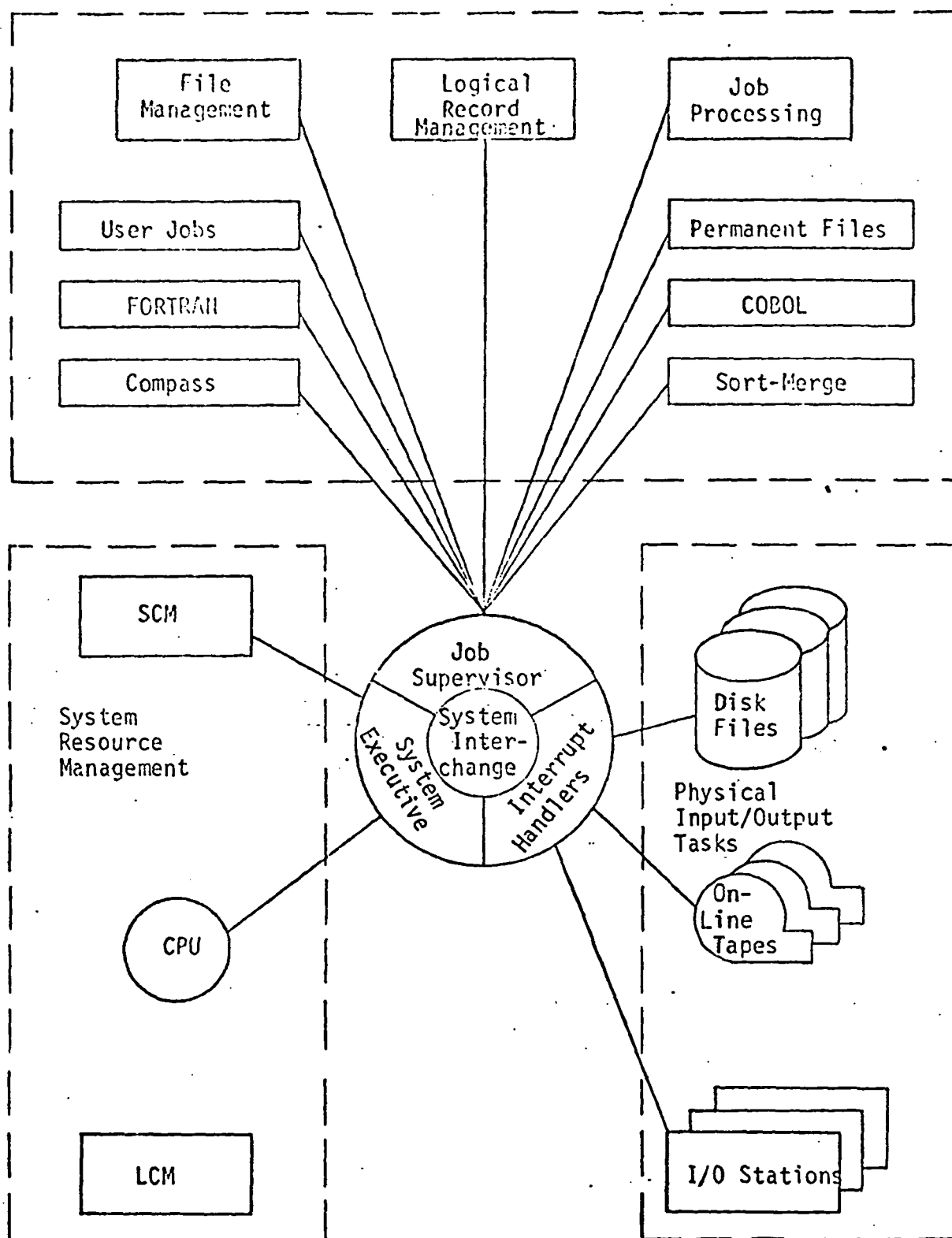


FIGURE 3.2.5-4

of the user's job and user requested system services, such as TIME, DATE, etc.

There are three sub-divisions of the system executive. The three parts represent a priority sequence based on the time sensitivity of the classes of activities listed. The E3 level, or real-time interface has highest priority. The E2 level contains I/O functions. Because interrupt service is involved, the E2 level is given preference over the administrative functions of the system executive which are grouped at the E1 level.

One job at a time is connected to the system interchange and, as the job completes its fraction of CPU time assigned to it, the job scheduler attaches a different job supervisor and its related job to the system interchange for execution.

• Station Communication

Stations submit job files and data files to the SCOPE 2 operating system and receive user created output data files. Files are processed according to type: permanent files, magnetic tape, line printer, or card punch, etc.

The stations also provide the station console operator with communication features for monitoring the progress of and controlling jobs executing under SCOPE. SCOPE responds with messages or displays presented on the CRT of a station console. Displays, operator requests, and other operator messages are described in the operator's reference manual for the appropriate station.

• Job Processing

A job first enters the system when a job input file is created at a station. The station formats the file and transfers it to the central computer where the job is queued for execution. The system allocates resources to the job as needed for execution.

The operating system interprets the control statements, calls the loader, calls compilers, and assembler, performs file manipulations and I/O, and provides permanent files as requested by the user.

SCOPE terminates the job by disposing of all files used or created by the job, by preparing the job's OUTPUT file for transmission to a station, and by de-allocating all resources used by the job.

Any file created by a job for transmission to a station, is queued in the central system and sent upon request by the station to be written on the appropriate peripheral device.

• Multi-Programming and Job Scheduling

SCOPE 2 provides multi-programming of jobs throughout the system. Multiple jobs reside in SCM, in LCM, and on system mass storage concurrently. The number of jobs residing in either SCM or LCM is a function of the job mix. The maximum number of jobs to be executed simultaneously is specified by installation parameter (maximum 4,096).

Access to the CPU and memory residence for all jobs in execution is reassessed on installation defined intervals, facilitating job progression on a priority basis.

The user may select job priority by job statement parameter or accept the default priority supplied by SCOPE. Once a job resides in the system, the external priority of the job does not change.

Job scheduling establishes job's residence progressively through three storage media: mass storage, LCM, and SCM. Jobs receive an aging increments while waiting in mass storage and LCM to ensure that no job is denied a chance to execute in SCM. Job field length requirements are evaluated against available memory to maximize use of large and small core memory.

- Memory Usage and Control

Each job while executing occupies contiguous address in SCM and/or LCM. Each job area is defined by reference addresses (PAS for SCM, RAL for LCM) and field lengths (FLS for SCM, FLL for LCM). If a program refers to an address outside its field length, hardware senses the error and range error processing occurs. The user may specify the action to take or simply allow job termination to occur. This memory protection hardware provides integrity in a multi-processing environment. Exit from a user program to the system (a hardware protected area) for processing of action requests is accomplished by execution of a monitor jump instruction.

Each job's field length contains an area (RAS+0 through RAS+77<sub>8</sub>), reserved for communication with the system. Loader information, control statement images, and other job related information are maintained in this area. File related communication occurs via the file information table, which is declared and maintained in the user's field length.

An extension to the user field length is provided for every job to enable the execution of various system elements which service the user field length. In addition, this extension area contains exchange packages for the job, which contains the job's normal and abnormal exits, and memory field lengths and reference addresses. The system maintains the exchange packages for all executing jobs.

- Record Management

The record manager services user's input/output requests.

The record manager provides flexibility to the user in specifying I/O requirements, and performs required data movement automatically during execution. For instance, the user may either choose to be completely



free of details of physically record formats (such as tape or disk formats), device assignment, and physical I/O, or specify them in detail by overriding default conditions.

#### 3.2.5.3.1.4.3 System Synchrony

- Real time clock interval is 27.5 nsec.
- Interrupts can be set and controlled by the system.
- Jobs can be started by dependency criteria.
- System runs jobs on basis of type and priority.
- The PPU I/O system does not affect CPU operation until the software determines that it is necessary.

#### 3.2.5.3.1.4.4 Global and Common Reference

Blank (Global) and labelled common features are available.

#### 3.2.5.3.1.4.5 Link Edit or Collection

The SCOPE loader provides object time organization necessary for program execution. The loader translates programs, subprograms, or overlays in relocatable format into core image modules in absolute form for execution.

The loader also performs tasks for the user such as searching of user and system libraries to satisfy program directives for loading and linking memory references, and establishing entry addresses.

#### 3.2.5.3.1.4.6 Interrupt Structure

Interrupt capabilities exist for I/O, arithmetic fault, memory range, and memory fault conditions.

#### 3.2.5.3.1.4.7 Program Residency/Non-Residency

The capability for program overlay structure exists within the confines of the loader. In addition, LCM can serve as a zero access storage media for these overlays.

3.2.5.3.1.4.8 Language Processors

Capability exists to use intermixed Fortran-Assembly Language Code. These can be linked into one piece by the loader. The FORTRAN compiler includes ANSI options.

3.2.5.3.1.4.9 Libraries

Library features allow for global, compiler, macro, and user (i.e., mathematical) libraries.

3.2.5.3.1.4.10 Computer System Accounting

System information file includes date, time, control card, job accounting summary, site designed accounting controls, station messages, error (hardware) conditions, etc. An analysis program (part of the system) extracts and builds reports and graphs of various message types and times.

3.2.5.3.1.5 Environmental Requirements

The system will have the following facilities requirements:

- Space: A minimum of 2800 sq. ft. (not including work area or customer engineering office space).

- Cooling: 325,765 BTU/Hour air dissipation.

422,125 BTU/Hour chill water dissipation

- Power: 1 - 25 KVA motor generator

1 - 40 KVA motor generator

127 KVA 60-cycle power for individual devices.

3.2.5.3.1.6 Cost Estimate

\$9 to \$10 million.

### 3.2.5.3.2 IBM S/370 MP/11 168 Computer System

The IBM Computer System consists of two S/370 M168 main frames connected together by a 3068 Multi-System Unit, which creates an MP 168 computer configuration with 4 million bytes fully shared memory. See Figure 3.2.5-5.

#### 3.2.5.3.2.1 Host Computer System

##### • MIP Capacity

- Each M 168 main frame can execute in excess of 4.0 MIP.
- 2-M 168's will have in excess of 8.0 MIP.

##### • Word Size

- 32-bits

##### • Fixed Point

- Single Precision - sign + 31 bits
- Double Precision - sign + 63 bits

##### • Floating Point

|                      | <u>Sign</u> | <u>Exp</u> | <u>Fraction</u> |
|----------------------|-------------|------------|-----------------|
| - Single Precision   | 1           | 7          | 24              |
| - Double Precision   | 1           | 7          | 56              |
| - Extended Precision | 1           | 7          | 112             |

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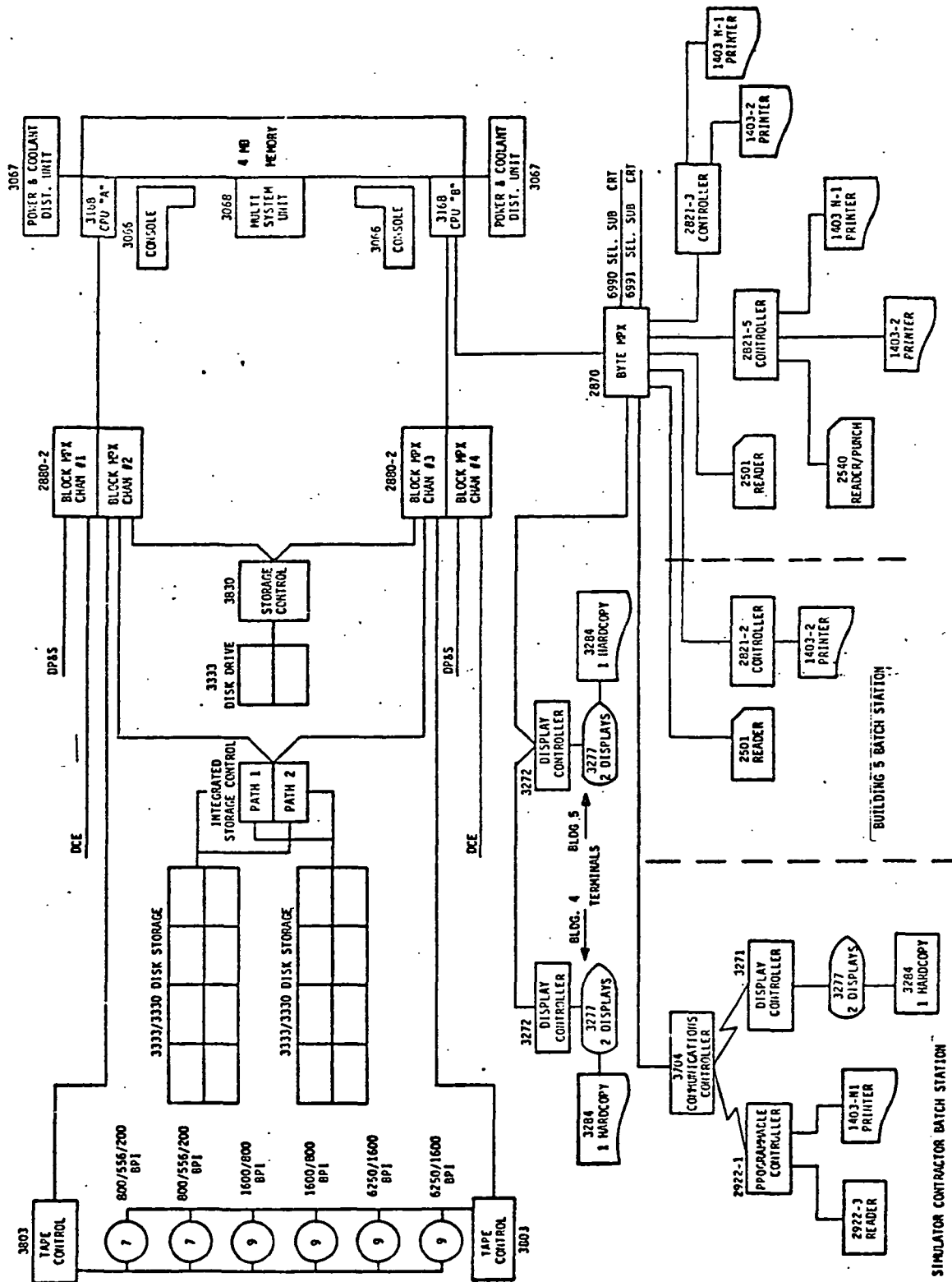
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IBM MP/168 CONFIGURATION

FIGURE 3.2.5-5

● Registers

- 16 general purpose (Fixed Point, 32-bits)
- 4 Floating Point (64 bits)

● Instruction Set Class

- Load/Store
- Arithmetic
  - Binary
  - Decimal
  - Floating Point
  - Fixed Point
- Logical
- Test/Branch
- Search/Compare
- Shift
- Index
- Byte/String Manipulation
- Supervisory

● Storage

- Buffer storage
- 80 ns cycle time
- 4 parity bits/words
- 8K bytes expandable by 8K to 16K

● Processor Storage

- 1 Million bytes, expandable to 8 million bytes in 1 million byte increments.

- 4 way double word interleaved access

- 8 byte wide data path
- Read/write cycle time of 480 ns for 8 bytes on double word bound.
- Partial write time of 800 ns.
- CPU data fetch (double word) takes 560 ns.
- In cases of simultaneous memory requests to same storage module, satisfaction is based upon requesting priority at storage control unit.
- Error checking and correction code.

#### 3.2.5.3.2.2 Central Processing Unit

##### • Features

- 4 deep instruction stack
- A double word from instruction stream can enter instruction buffers every 80 ns.
- Dynamic address translation allowing virtual storage to 16 million bytes.
- High speed multiply feature.
- Automatic instruction retry.
- Time of day clock.
- Store and fetch protection.
- Writable and read only control storage.
- Integrated storage control.

#### 3.2.5.3.2.3 Time Sharing Equipment

##### • 3271 Display Controller

- Buffer capable of handling devices of up to 1920 characters.
- Can attach up to 32 separate I/O devices.
- Permits transmission speeds of 1.2K, 2.0K, 2.4K or 4.8K BPS.
- Permits remote attachment to S/370.

• 2922-1 Programmable Controller

- Contains 8K bytes of addressable program and data storage.

Each byte can store alphanumeric, binary or logical data.

- Provides eight general registers, including direct addressing capability.

- Operates with fixed point and packed decimal arithmetic.

Included are multiply, divide, edit and translate instructions.

- All functional switches and lights are located on the controller console.

• 2922-3 Card Reader

- Provides card input for the controller at speeds up to 500 cards per minute.

Can read all EBCDIC codes as well as binary cards.

- Equipped with a 1200 card hopper and 1300 card stacker.

• 3272 Display Controller

- Permits local attachment to S/370.
- Buffer capable of handling devices of up to 1920 characters.
- Provides attachment of up to 32 separate I/O devices.
- Permits speeds of up to 650KC/sec.

• 2501 Card Reader

- 600 card/minute
- Can read all 256 EBCDIC punches.

• 1403-02 Printer

- 132 print positions.
- 600 lines per minute

#### 3.2.5.3.2.4 On-Line Peripheral Equipment

- o 2880-2 Block Multiplexer

- Operates in selector or block MPX mode.
- Transfer rates to 3.0 MB/sec
- Channel indirect addressing.
- 2 byte interface.
- Can connect up to 8 controllers/channel
- Can attach channel - channel adaptor

- o 2870 Byte Multiplexer

- Operates in byte or burst mode.
- May have selector subchannels.
- Channel indirect addressing.
- Can connect up to 8 controllers/channel.
- Can attach channel - channel adaptor.

- o 3333/3330 Disk Drive

- Each pack has approximate capacity of 100 M bytes.
- Average access time - 30 ms
- Average rotational delay - 8.4 ms.
- Rotational position sensing.
- Can service multiple requests.
- Two channel switch.
- Transfer rate 806 KB/sec.



- 3803 Tape Controller
  - Two channel switch.
  - Handles 7 and 9 track drives.
  - Data rates from 60 to 1250 KB/sec.
- 3420-8 9 Track Tape Drive
  - 6250/1600 BPI - 1250/320 KB/sec.
- 3420-5 9 Track Tape Drive
  - 1600/800 BPI - 200/100 KB/sec.
- 3420-3 7 Track Tape Drive
  - 800/556/200 BPI - 60 KCS
- 1403-N1 Printer
  - 132 print positions.
  - 1,100 lines per minute.
- 2540 Card Reader/Punch
  - Read 1000 cards per minute.
  - Punch 300 cards per minute.
  - Can read and punch simultaneously.

### 3.2.5.3.2.5 Operating System

The candidate operating system is the System/370 Operating System/Virtual Storage 2.2, which is a generally compatible extension of OS/360 MVT. VS2.2 is a virtual storage system with time-sharing and multiprocessing support integrated into the control program. In addition, the design provides the potential for the concurrent execution of time-sharing, background, and real-time jobs.

- Overhead

The amount of real memory and CPU time used will be dependent upon the options selected and services used. A reasonable estimate of resources used would be 10 - 15%, time and core (i.e., ~.4 MIP, 300K Bytes).

- OS/Simulation Software Interface

The VS2.2 operating system provides most of the required system facilities and services to implement the simulation software system. Facilities and services that must be added, (e.g., special device support), may be installed using standard features of the system.

- Synchronization of Parallel Execution

VS2.2 contains all necessary logic and controls to fully integrate a two CPU complex into one total computer resource. This is accomplished by having each CPU execute one common operating system. Thus each CPU is fully aware of the actions and status of the other CPU.

- System Synchrony

- Interval Timer

This timer provides program interruption on a program-controlled

basis. The timer, which is updated by timing circuits, has a time resolution of 3.333 milliseconds.

- Time-of-Day Clock

The clock's binary value, updated each microsecond, can be interrogated or set by provided instructions.

- Clock Comparator and CPU Timer

The clock comparator causes an external interruption when the time-or-day clock reaches a value specified by the user.

- Priority Structure

VS2.2 supports a complete multi-level priority structure throughout the system. This structure may be dynamically modified by the user programs.

- Global and Common Reference

The standard compilers and program products, (e.g., PL/I) provide for global and named common data areas.

- Link Edit or Collection

- Linkage Editor

The linkage editor combines separately compiled or assembled object modules into a single program that is ready to be loaded and executed. It also combines previously edited load modules with each other or with object modules, and enables changes to be made in a program without recompiling (or reassembling) the complete program; only those sections that are changed need to be recompiled.

- Interrupt Structure

The computer interruption system separates interruptions into five classes:

Supervisor Call interruptions are caused when the program issues an instruction to pass control to the part of the control program which performs the supervisory functions associated with a task.

Program interruptions are caused by various kinds of programming errors and exceptions.

Machine Check interruptions are caused by the machine-checking circuits detecting an error.

I/O interruptions are caused by and I/O unit ending an operation or otherwise needing attention.

External interruptions are caused by an external device that requires attention, by the interval timer going past zero, or by the operator pressing the interrupt key. Provision is made for user handling of external interrupts.

- Program Residency/Non-Residency

Executable user program segments which cannot be accommodated in the real memory of the user's system may be loaded into real memory for execution via the VS2.2 demand paging function, giving the computer the appearance of having 16 m bytes of storage, standard VS2.2 overlay facilities, or a user written overlay handler.

- Language Processors

- VS2.2 system assembler

A-macro assembler which translates a symbolic language into machine language relocatable object code.

- Fortran IV

- System Utilities

An extensive library of facilities and services are provided by utility routines to simplify and enhance utilization of the system.

- Mathematical Library

A comprehensive library of mathematical subroutines are supplied in the Fortran IV library. This library also includes input/output support routines for use by fortran programs.

- Macro

A macro library providing access to the complete VS2.2 system capabilities is supplied. The ability to add installation defined macro's is inherent in the library.

- o Computer System Accounting

- Two standard measurement facilities are included in VS2.2:

- System Management Facilities (SMF) provide the means to gather and record information that can be used for user accounting or for evaluating system use. SMF is basically job and terminal-session related.

- The system activity Measurement Facility (MF/1) collects information about system activity and produces trace records and reports. MF/1 is basically system-oriented; it is designed to aid the installation in improving system performance, analyzing system trends, and evaluating future system requirements.

### 3.2.5.3.2.6 Environmental Requirements

- o Electrical Requirements

- 250 KVA

- o Cooling Requirements

- Air 700,000 BTU/HR

- Chilled water 500,000 BTU/HR

- o Floor Space

- 1,920 Sq. Ft.

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3.2.5.3.2.7 Cost

\$9 to \$10 million.

### 3.2.5.3.3 UNIVAC 1110 Computer System

The Univac Computer System shown in Figure 3.2.5-6 is comprised of two central complexes (System I, System II), each of which is a Univac 1110 Computer. The on-line peripherals have been configured so that each computer has full access capability to each device. The full access capability has also been utilized in the configuring of the remote batch stations, interactive terminals, and the essential hardware elements of each crew station.

#### 3.2.5.3.3.1 Computer System(s)

- MIP Capacity: 6.0 (System I)  
3.0 (System II)

TOTAL: 9.0

- Word Size: 36 Bits

| <u>Floating Point</u> | <u>Sign</u> | <u>Exponent</u> | <u>Fraction</u> |
|-----------------------|-------------|-----------------|-----------------|
| Single Precision      | 1 Bit       | 8 Bits          | 27 Bits         |
| Double Precision      | 1 Bit       | 11 Bits         | 60 Bits         |

- Fixed Point

Single Precision Sign Bit + 35 Bits

Double Precision Sign Bit + 71 Bits

- Primary Storage (PSU): 262K (System I)  
262K (System II)

TOTAL: 524K





## Features:

- 280 nanosecond read
- 480 nanosecond write
- 650 nanosecond partial write
- Word size = 36 bits
- 8,142 word memory
- Simultaneous access to each module in a storage unit
- Parity Checking
- Access through each MMA by up to four CAU's and four IOAU's
- Expandability in 32K word increments up to a maximum of 262K words
- Interleave access (odd-even addressing to two adjacent 8K modules)
- Access conflicts resolved for 8K word modules
- Partitionable in 32K word increments

• Multiple-Module Access (MMA) Section

## Features:

- Provides eight priority - ordered connection paths to each of the storage modules in the PSU.
- Number of paths may be expanded to 16.
- Each CAU requires two paths (operand and instruction)
- Each IOAU requires one path
- The basic MMA contains four preemptive paths for IOAU use and four non-preemptive paths for CAU use.
- MMA expansion paths are non-preemptive only.

• Extended Storage (ESU)

232K (System I)

131K (System II)

TOTAL: 363K

## Features:

- 1.5 psec read/write/partial write cycle time
- 131K words/unit
- Expandable to 8 units (1M word) per system
- Parity checking for data, address information and read/write control information
- Connected via the MAI to the CAU and IOAU

• Multiple Access Interface (MAI)

Each MAI module operates in the same manner as the MMA. One MAI is required for each ES unit.

• Command/Arithmetic Unit (CAU)

## Features:

- 4-deep instruction stack
- Interface capability: 4 PSU's (via MMA's)  
8 ESU's (via MAI's)
- Overlapping and interleaving of data paths
- Can logically be removed from system for maintenance without affecting the remainder of the system
- CAU to CAU communication via interprocessor interrupt lines
- One CAU can interface with two input/output access units
- 300 nanosecond effective basic instruction time

- MIP rate: 1.4 - 3.0/CAU
- Input/Output Access Unit (IOAU)

Features:

  - Provides control and data paths between main storage and peripheral subsystems.
  - Allows data transfer to occur without affecting the instruction cycles of the CAU.
  - Minimum of eight channels.
  - Expandable in increments of eight to 24 channels.
  - Data chaining provided scatter/read, gather/write
  - Interfaces to CAU, storage, system partitioning unit (SPU), peripheral subsystems.
  - Aggregate transfer rate: 4M words/second
  - Parity checking of input/output transfers
- System Partitioning Unit (SPU)

Features:

  - Partitions large systems into two or three smaller systems.
  - Isolates units and takes them off-line for maintenance, without disrupting the rest of the system.
  - Provides system monitoring.
  - Allows automatic recovery procedures.
- General Registers: 112 (36 bits/register)/CAU
- Instruction Class

|                |                          |
|----------------|--------------------------|
| Load/Store     | Arithmetic: Binary       |
| Logical        | Decimal                  |
| Test/Branch    | Floating Point           |
| Search/Compare | Fixed Point              |
| Shift          | Byte/String Manipulation |
| Index          | Supervisory              |

- UNISCOPE 100 Display Terminal

The UNISCOPE 100 Display Terminal is an alphanumeric display that is designed for a broad range of applications which require direct operator interaction with a centralized computer system. Due to its modular construction, the UNISCOPE 100 terminal operates either as a data entry or as a display device.

### 3.2.5.3.3.2 Time-Sharing

- The UNISCOPE 100 Terminal

The UNISCOPE 100 Terminal is a self-contained unit consisting of a cathode-ray tube display screen, refresh memory, character generator, control logic, operator keyboard, and communications interface. Special interfaces for direct computer connection and hard copy output are also available. A variety of presentation formats are offered which provide a total display capacity of 480, 512, 960, or 1024 ASCII characters. The complete ASCII set of 96 characters can be displayed (includes upper and lower case alphabets). Hardware editing capabilities enable the operator to completely edit any message prior to transmitting the message to the computer.

Sixteen UNISCOPE 100 terminals may be connected to a single communications line modem or to a computer input/output channel by means of multiplexers.

- Remote Batch

Simulator Contractor Site

- 1 9300 Processor (8K bytes storage)
- 1 Printer 600 LPM
- 1 Printer 900 LPM
- 1 Reader 1000 CPM

- 1 Punch 250 CPM
- 1 Data Communications Subsystems (40.8 KBPS?)

#### Building 5

- 1 9300 Processor(8K bytes storage)
- 1 Printer 600 LPM
- 1 Reader 600 CPM
- 1 Data Communications Subsystem 9.6 KBPS

#### • UNIVAC 9300

The UNIVAC 9300 System is used as a remote subsystem to the central computer. The UNIVAC 9300 system is linked to transmission facilities through the GPCC CLT, with the transmission facilities being connected to the central computer through the C/SP.

The UNIVAC 9300 system is an internally programmed computing system which offers both an 80-column card processing capability and a high-speed magnetic tape system. The computer is equipped with all functions for execution of instructions including arithmetic and input/output control. The integral card reader, card punch, and line printer offer higher speeds than those available on the smaller UNIVAC 9200 system. The multiplexer I/O channel of the UNIVAC 9300 system can accommodate up to eight peripheral subsystems. Maximum storage size is 32,768 bytes of plated-wire storage with a cycle time of 600 nanoseconds.

### 3.2.5.3.3.3 On-Line Peripherals

#### • Communications/Symbiont Processor (C/SP)

General: The UNIVAC Communications/Symbiont Processor is a high performance, internally programmed system which is intended to absorb the combined symbiont functions of communications control and paper peripheral control. Its high speed internal operation and flexible I/O channels provide high throughput rates and a universal interface for all types of communications facilities and terminals.

#### • Processor Characteristics

The major features of the processor include the following:

- 52 half-word and full-word instructions
- Sixteen 32-bit general purpose registers, external to storage
- Attached processor maintenance panel
- I/O interrupt and data priority controls
- Interval timer (6ms resolutions)
- 16 bit data path
- Multilevel interrupt
- 630 nanosecond cycle time
- Basic binary add (RX) instruction time of 2.52 ps (four cycles)
- Binary add instruction (RR) time of 1.26 ps (two cycles)

#### • Interrupts

The interrupt system provides an automatic means of alerting the C/SP processor to exceptional or unexpected conditions, such as the end of the I/O operations, program errors, machine errors, and similar occurrences and directs the processor to the appropriate program routine following their detection.

Storage• Main Storage Characteristics

The main features of main storage include the following:

- Capacity: 32,768 bytes minimum; 131,072 bytes maximum
- Cycle time: 630 nanoseconds read/write/cycle
- Operating mode: nondestructive readout
- Storage data path: 18 bits wide (two 8-bit bytes and two parity bits)
- Addressing: zero time indexed base and displacement  
double indexed
- Storage protection: program and I/O transfer
- Parity: odd parity (one parity bit per byte)

• Addressing

The addressing hardware accommodates a 17-bit address field which permits one cycle addressing of 131,072 bytes.

Channels

All information transmission in and out of the C/SP is handled by channels. The features of the C/SP channels are:

- Direct interface to storage
- Independent operation
- Simultaneous operation
- Priority interchangeability

The C/SP may contain up to seven channels, numbers 0 to 6.

Priority of these channels increases in descending channel number order, Channel 0 having the highest priority.

- Channel Types

The C/SP is equipped with the following four types of channels:

- Special Device Channel (SDC)

The primary function of the SDC is to provide the means for local program loading and maintenance of the C/SP using a serial 80 column, 80 card per minute, card reader device.

- 1100 Series Adapter Channel

The 1100 Series Adapter Channel (intercomputer adapter channel) provides an interface for direct communication between the C/SP and an I/O channel of a UNIVAC 1100 Series Computer. The maximum transfer rate is in excess of 300,000 words (36 bits each) per second.

- Multiplexer Channel

This channel provides the capability of attaching all currently available UNIVAC 9000 Series peripheral devices, which operate on a corresponding channel to the C/SP. In addition, the high speed card reader and the ASCII printer can be connected via the channel.

- General Purpose Communications Channel (GPCC)

The GPCC and associated components are described below.

- General Purpose Communications Channel (GPCC)

The GPCC performs such functions as multiplexing the various communications line terminals (CLT) so that one CLT may be serviced at a time, recognizing special characters and sequences of characters, checking character parity, coordinating all data transfers to and from storage, and executing other necessary operations.



The CLT's perform the functions of assembly and disassembly of data characters for proper reception from and transmission to a communication line, detection of certain conditions of the communication line such as loss of carrier, a ringing indication, and others; and establishment of character synchronization.

The multiplexer portion of the GPCC accents up to 64 simultaneously presented service requests from the CLT's plus an external function (XF) request from another portion of the GPCC. The multiplexer selects one request by connecting the selected CLT to the GPCC.

• 2 Line Printers

- 2 900 LPM
- 2 1200 LPM

• Card Reader

- 2 1000 CPM

• Card Punch

- 1 250 CPM

• High Speed Drum Subsystem

|                | <u>Average Access</u> | <u>Capacity</u>           |
|----------------|-----------------------|---------------------------|
| 6 FH432 Drums  | 4.25 mil              | 4.7 million char.         |
| 2 FH1782 Drums | 17.0 mil              | <u>12.5 million char.</u> |

System Total:

43.2 million char.

- Dual Access Capability

363<

- Mass Storage Disc Subsystem

|                           | <u>Average Access</u> | <u>Capacity</u>    |
|---------------------------|-----------------------|--------------------|
| 4-8440 Disc Storage Units | 30 mil.               | 960.3 Mil. Char.   |
| Two System Total:         |                       | 1,920.6 Mil. Char. |

- Two independently addressable disc drivers per unit.
- Dual access capability.

- Tape Subsystems

|                          |                 |         |
|--------------------------|-----------------|---------|
| 2 UNISERVO 16 Tape Units | 1600 BPI        | 9-track |
| 4 UNISERVO 16 Tape Units | 1600/800 BPI    | 9-track |
| 2 UNISERVO 16 Tape Unit  | 200/556/800 BPI | 7-track |

- Dual access capability.

### 3.2.5.3.3.4 Operating System (OS)

The UNIVAC 1110 system is the logical successor to the UNIVAC 1106 System and the UNIVAC 1108 Multi-Processor System. Designed to enhance the efficiency of the UNIVAC 1100 Series, the UNIVAC 1110 System offers dependable and highly effective processing in real time, demand, and batch mode, and excels in multiprocessing time-sharing applications.

- User Timer

This register is initially loaded by the program. The contents are then decremented once each 200 microseconds. A real time clock interrupt occurs when the clock count is decremented through zero. Thus, if the clock is initially loaded with the value 5000, an interrupt occurs in exactly one second.

- Synchronization of Parallel Executions

In the proposed UNIVAC 4X2 and 2X1 1110 configurations, the initiation, synchronization, and termination of execution sequences can be accomplished by special ER's (Executive Requests).

- Re-Entrant Code Generation

UNIVAC supports all forms of re-entrant processing for users of the 1100 System. The FORTRAN, COBOL, and ALGOL processors and libraries are provided as a set of re-entrant modules. The FORTRAN and COBOL compilers produce re-entrant code and can be used to produce re-entrant processors for local use.

- System Synchrony

- Real-time clock
- A user-written ER (Executive Request) can be written and included in the set of ER's for: initializing the Real Time Clock with a time-value and receiving an interrupt when the time-value is expended.
- A special ER (RT\$) allows alteration of priorities of program modules.
- Priority Structure: 1100 Operating System supports a complete multi-level priority structure throughout the system.

- Link Edit or Collection

The UNIVAC 1100 Series Operating System provides the ability to combine the relocatable elements generated by a language processor into an executable (absolute) element. This combination or collection of relocatable elements is done by a system processor, the collector.

- Interrupt Structure

Specific interrupt locations are assigned within the lower addresses of a main or extended storage module as specified by a 9-bit module select register (MSR). These interrupt locations are programmed to capture the interrupted address and enter interrupt response subroutines in the executive system. The synchronization of input/output activities and response to real time situations are accomplished through some of these interrupts.

Other interrupts are provided for certain error conditions detected within a CAU or IOAU. These may result from a programming fault such as an illegal instruction, a storage parity error, or a user program violations such as an attempt to write into a protected area of storage or a violation of guard mode.

- Program Residency/Non-Residency

1100 Operating System supports two levels of program segmentation. One level is the classical overlay segment which physically, via I/O, replaces part of an existing program. The program bank concept provides a virtual storage mechanism for the 1100 series programmer. The Executive System in this manner currently supports a virtual space of nearly 67 million 36-bit words (over 267 million bytes). Half of the banks are available to the programmer for the individual program and the other half is reserved for common routines including the re-entrant subroutines libraries. Each bank (segment) may be specified as static (always available) or dynamic (load on request). Static banks are kept resident in memory any time the program is active, Dynamic banks are loaded upon request, and if

space is needed, are the first to be removed from memory when the program is no longer accessing them. This form of segmentation preserves the contents of a segment when a new segment is accessed, which is not the case for overlay segments. The 1110 hardware provides bank referencing instructions which operate as subroutine call instructions in that they provide for return to the calling bank.

In the 1110 System, four of the possible 510 banks are accessible at any given time without requiring use of the bank referencing instructions.

- Language Processors

- The UNIVAC 1100 Series Assembler

The UNIVAC 1100 Series Assembler translates a symbolic language composed of brief expressions to machine-language relocatable object coding for the UNIVAC 1110 System.

- FORTRAN V

FORTRAN V has all the features of the proposed American National Standard FORTRAN IV language plus many valuable extensions which significantly increase the power and flexibility of the language, particularly in the areas of data handling.

- Libraries (System Utilities)

The system includes a set of auxiliary processors which perform functions that complement those of the source language processors such as FORTRAN, COBOL and Assembler. This set of processors includes the Collector for linking relocatable subprograms, the Procedure Definition Processor for inserting and modifying procedure definitions in a library,

the ELT Processor used to insert elements, the Data Processor to introduce data descriptions. A comprehensive set of library elements complements these processors.

Included within the Utilities section of the Executive System are diagnostic routines, program file manipulation routines, file utility routines, and cooperative routines which aid the user by performing such functions as reading cards, printing line images, transferring files from device to device, and carrying out housekeeping functions required for file-residence on mass storage devices.

- Math-Pack

Math-Pack provides the UNIVAC 1110 System with a comprehensive library of 84 fundamental mathematical subprograms coded in FORTRAN V.

- Stat-Pack

Stat-Pack provides the UNIVAC 1110 System with a comprehensive library of 91 fundamental statistical subprograms coded in FORTRAN V.

- Macro

Extensive macro capability (Procedures or PROCs) is an integral capability of the Assembler.

- Computer System Accounting

To facilitate examination of user environment, UNIVAC provides a system within the Operating System to collect data during operation. This performance measurement system is the Software Instrumentation Package (SIP).

SIP consists of a set of routines within the Executive which collects data, and a series of user-level data reduction programs. Statistics

are gathered on such things as CPU, storage and I/O channel utilization, file placement and accesses, etc.

• C/SP Software

The software support provided for the C/SP is designed to provide complete flexibility for implementing a symbiont subsystem and for handling communications configurations with all types of terminal hardware while maintaining an expedient user interface. Coding efficiency, is achieved by the utilization of a powerful instruction set at the assembly level. System macros are also provided to facilitate the user's requirements.

Software to integrate the UNIVAC C/SP effectively with the host computer system is supplied; an assembler and simulator to write and debug user own code on the larger system also are included.

The software package is divided into three segments: (1) resident programs and routines; (2) programs to operate under the host computer executive system; and (3) modification to host computer elements.

Each of these segments is discussed in further detail in the following paragraphs.

- Resident Programs

The resident program software elements are defined as programs which reside entirely or partially in C/SP main storage during their execution. Resident programs include:

Operating System

Diagnostic Routines

- Intercomputer Handler

- Operating System

The UNIVAC C/SP Operating System comprises various program

modules which are specified by the user at system generation. When supplied elements are used, the following are included:

Terminal Management Supervisor (TMS)

Message Control Program (MCP)

Terminal Management Control Routine (TMCR)

Communication Control Routines (CCR)

Symbiont Control Program (SCP)

3.2.5.3.3.5 Environmental Requirements

o Electrical Requirements in KVA

- Non-regulated 208 V, 3Ø TOTAL: 244.0

o Air Conditioning

- BTU/Hr. 771,054

- CFM 67,714

o Approximate Floor Space

- 2730 sq. ft.

3.2.5.3.3.6 Cost Estimate

\$9 to \$10 million.



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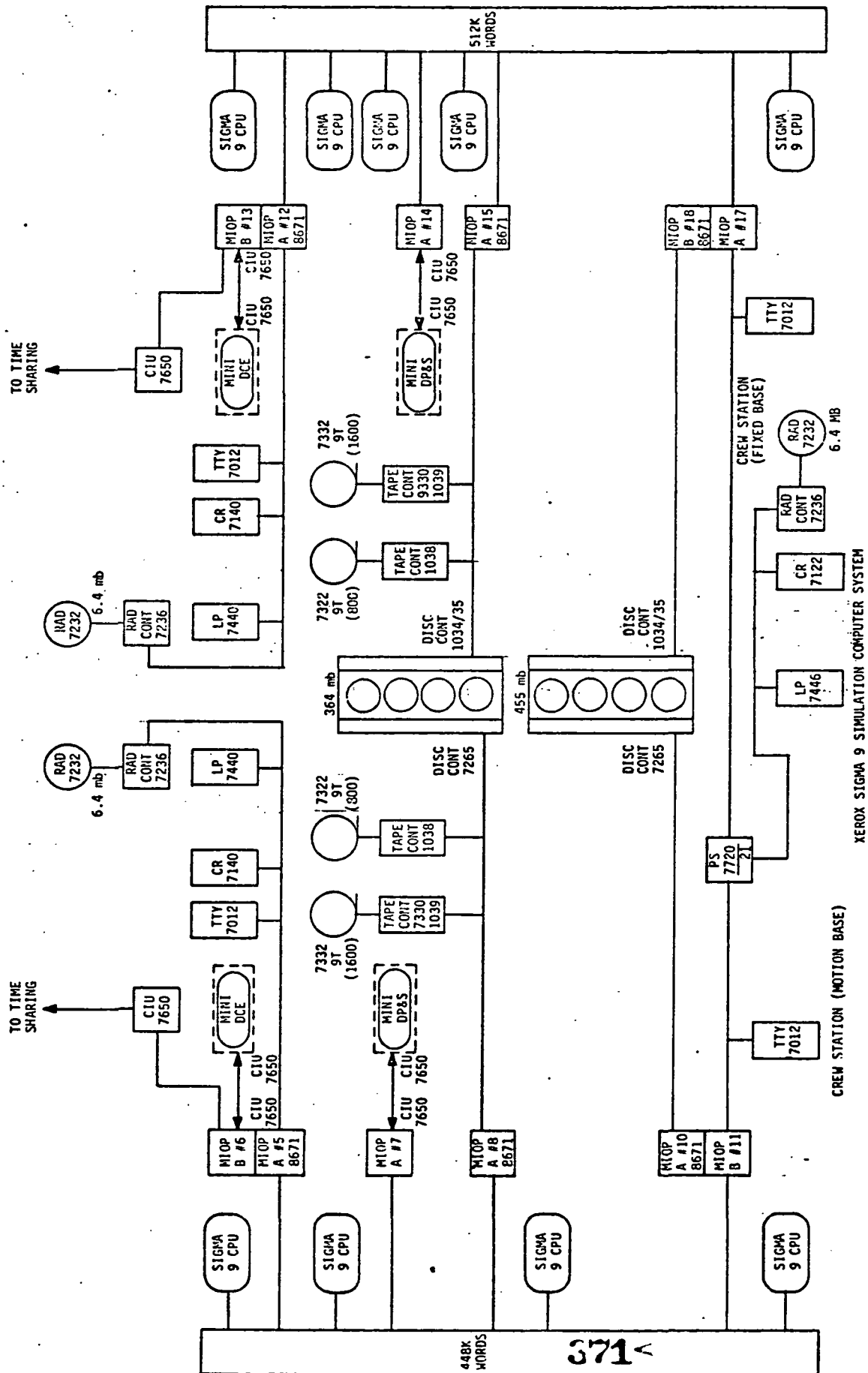
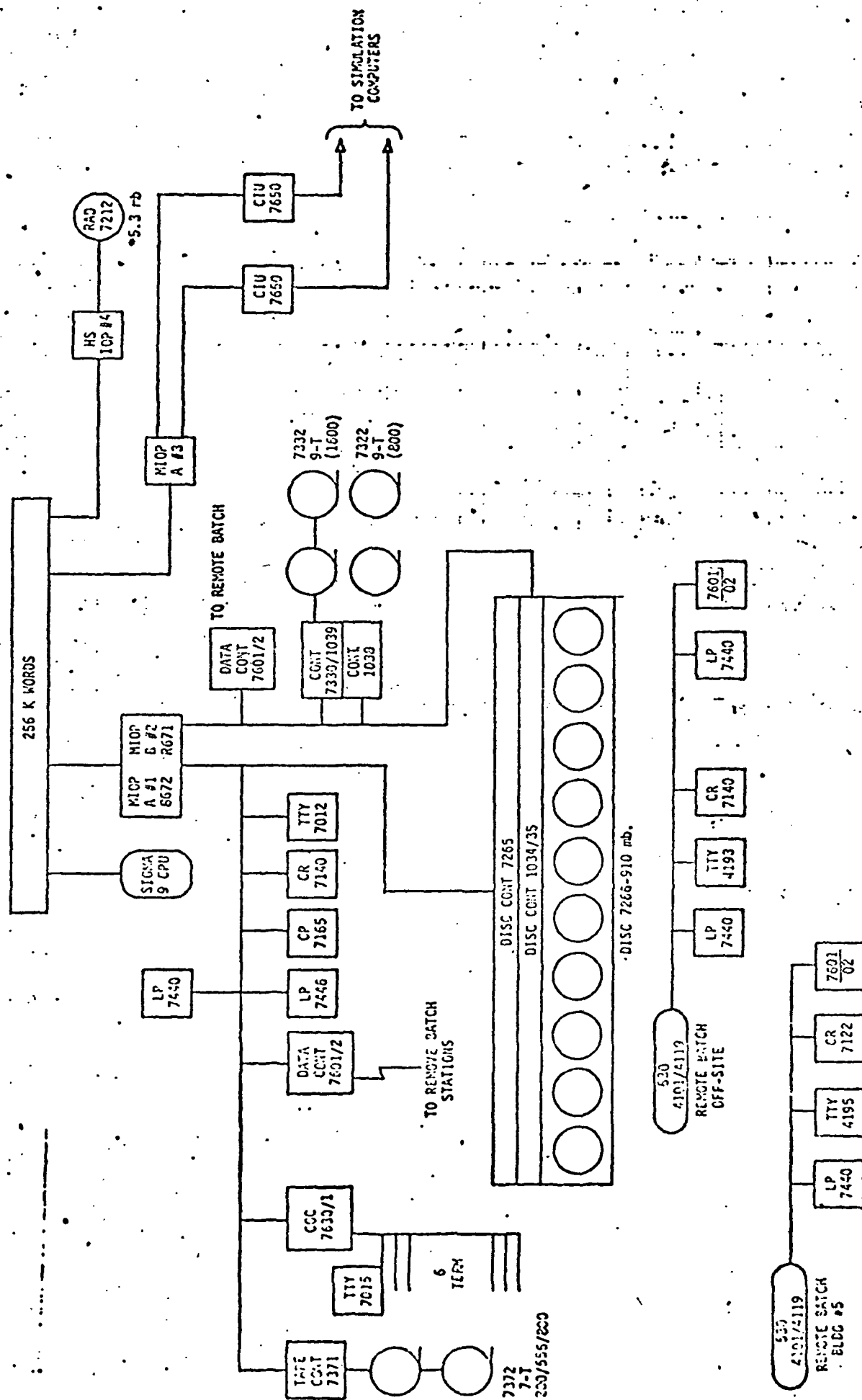
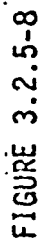


FIGURE 3.2.5-7



**XEROX SIGMA 9 TIME SHARING COMPUTER SYSTEM**



- Test/Branch
- Search/Compare
- Shift
- Index
- Byte/String Manipulation
- Supervisory

- o Registers: 16 general purpose
- o Extensive Interrupt Structure

#### Memory Hierarchy

- o Main Memory (all executable)

- Size

512K words (2048K bytes)

- Speed

900 nanoseconds

- Type

Core

- o Sigma does not support bulk or non-executable storage.

#### Configuration Features

- o Reconfiguration

Sigma is a flexible hardware system. A total reconfiguration capability (e.g., switching of CPU buses, I/O channel assignments, etc.) can be provided.

- o All Sigma computers and peripheral products are totally upward compatible.

- o Redundancy

A totally redundant system has been configured which emphasizes ease of failover.

- Multipathing

Sigma is designed as a multi-path system. Each CPU has its own data path to memory as does all I/O processors.

#### 3.2.5.3.4.2 Time-Sharing Equipment

Xerox provides an entire line of communication products including concentrators, front ends and RJE terminals. Items of interest include:

- Remote Job Entry

- Intelligent terminal

Xerox 530

- DCT2000, 225 LPM

250 CPM, 2251 LPM

- Interactive Devices

- Teletypes

10 CPS

#### 3.2.5.3.4.3 On-Line Peripheral Equipment

- Magnetic Tapes

- 9 track, 1600 BPI, 120KB and 240KB

- 9 track, 800 BPI, 60KB and 120KB

- 7 track, 200/556/800 BPI, 60KB

- Removable Disk - High Density

- 91 Mega byte drive, 41.5 ms access, 513 KB

- Fixed - Head Disk

- 6.2 + Mega byte unit, 17 ms access, 384KB

- 5.3 + Mega byte unit, 17 ms access, 3.2KB
- Card Readers - 80 column, 1500 CPM, 400 CPM
- Card Punch - 80 column, 300 CPM, 100 CPM
- Line Printers - 132 print positions, 600 LPI, 1100 LPM, 1500 LPM

#### Operator Interface

- Console - Teletype, 10 CPS
- Maintenance Panels - included in hardware
- Time of Day - Displayed every minute upon operator's console

#### 3.2.5.3.4.4 Operating System - Control Program - Five (CP-V)

The core requirements for CP-V including system residency, system buffers and transient areas is 32K words. Based on the identified requirements, the worst case overhead for CP-V in terms of instructions per second is .2 MIPS when executing on a Sigma 9.

CP-V will provide a hospitable environment for real-time simulation software.

#### System Synchrony

- CP-V allows the user to access and control up to two (2) real-time clocks. Each clock can be individually set to any of four manually switchable frequencies: The commercial line frequency, 500<sub>HZ</sub>, 2000<sub>HZ</sub> or a user supplied frequency.

- User programs can establish and receive interrupts based on time intervals using the M:TIMER facility of CP-V.

- User programs have the capability to initiate and synchronize the execution of additional program modules through the GPOST job facility of CP-V.

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- CP-V provides for dynamic altering of execution priority for a task based on the functions currently being performed by that task (I/O, compute bound).

- CP-V provides a sophisticated priority structure for execution based on that task's mode of operation (batch, interactive and real-time). The selection priority for mode of operation is defined at system generation time, but can be altered dynamically by the operator.

- The Sigma architecture provides an extensive interrupt structure for the monitoring of external events. CP-V provides software support for controlling of interrupts so as to prevent loss of data. CP-V also allows the user to directly service selected interrupts if he so desires.

#### Global and Common References

- Most of the language processors which operate under CP-V allow the user to declare external definitions and references in his program. These include the following processors:

- Xerox Entended FORTRAN IV
- Xerox ANS COBOL
- Xerox META Symbol
- Xerox SL-I
- Xerox FMPS
- Xerox Data Management System

- The ability of program modules to share common data is provided by the various Xerox language processors.

The Xerox CP-V operating system provides a sophisticated

linkage-editor processor called a LOADER which allows the user to combine discrete software segments into executable modules. Xerox language processors generate object code such that routines written in different languages can be combined to form a single executable load module (i.e., a FORTRAN main program may have subroutines written in COBOL, FORTRAN, and META-SYMBOL (Assembler)).

#### Interrupt Structure

- The Sigma 9 provides a very extensive interrupt system including eight internal and fault interrupts, twelve traps (program faults), two (2) I/O interrupts and up to 224 external interrupts. These interrupts are controlled through an elaborate system of arms, disarms, enables, and disable flip-flops.

- Up to four real-time clocks are a part of the interrupt system and can be monitored by either the user or CP-V.

- The handling of internal and fault interrupts is reserved for CP-V. The user has the ability to handle all external interrupts or let CP-V handle them.

- The I/O system of CP-V allows the user the option to perform I/O with either wait or no wait specified. The no wait option allows the user to maintain control of the CPU instead of being forced to relinquish it upon initiation of I/O.

The CP-V supports both the paging or virtual memory technique and the overlay technique. The virtual memory support is CP-V's native mode and enhances total system performance and throughput.

#### Language Processors

- Xerox extended FORTRAN IV - (ANSI is a subset)



- Xerox META-Symbol (assembler)
- Xerox ANS COBOL
- Xerox Data Management System (data base)
- Xerox SL-I (continuous system simulator)
- Xerox FIPS (linear programming package)

The FORTRAN Language Processor allows the user the ability to insert symbolic code (assembly language) statements within his FORTRAN statements.

CP-V provides a host of libraries for the user. Included is a system utility package providing file and system maintenance routines. A complete statistical and mathematical library is available from the Xerox User's Group. To aid the user in using system procedures, a complete Macro library is available. User libraries are easily created and maintained.

CP-V provides comprehensive statistical gathering packages. Not only are standard user accounting statistics available (job execution time, resource usage summaries) but also statistics reflecting total system usage (I/O rates, I/O volume, CPU utilization, processor utilization, etc.). This information is made available to the installation in a file and may be accessed on-line or in batch. Also available to the installation is a series of programs which runs analysis on these statistics and helps the installation to better their system.

#### 3.2.5.3.4.5 Environmental Requirements

- Space
  - A maximum of 5400 sq. ft. will be required.
- Cooling
  - 1,125,300 BTU/Hour air dissipation

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#### 3.2.5.4 Mini Computer System Analysis

The computer which Singer has selected for input/output, interface and controller operations in the SMS is a 16-bit PDP 11/45 mini computer manufactured by the Digital Equipment Corporation. The PDP-11 was chosen from a variety of 16-bit computers as the best available machine for SMS applications.

Figure 3.2.5-9 illustrates the unique architecture of the PDP-11 in which elements of the system - central processor, high-speed core memory, disk storage unit, DMA interface controllers, a printer plotter, paper tape reader/punch, and Keyboard Printer (ASR-35) - are connected to a single bus. The concept of a unified bus - a single, long data path comprised of several separate signal wires - to interconnect processors, memories, and input-output elements, is being used on many of the newest computers. In these systems, all the devices send and/or receive addresses, data, and control information by means of the same set of signals, and all the devices are connected to the bus by means of a single, standard interface.

This approach and its resulting flexibility are in distinct contrast to the traditional computer architecture, which in most cases has called for three separate buses for memory, input-output and direct memory access (DMA). These are usually physically as well as functionally separate, and not designed to permit easy interchange of computer elements. Figures 3.2.5-9 and 3.2.5-10 illustrate the two

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different approaches.

UNIBUS\* is the name given to the single bus structure of the PDP-11. The UNIBUS concept is the key to many PDP-11 strengths. All system elements, including the central processor, communicate with one another in identical fashion. This gives the processor the same easy access to peripherals as it has to memory. Communication on the UNIBUS is bidirectional and asynchronous. Devices can send, receive and exchange data independently without process intervention or the need for special I/O instructions. For example, a CRT display can refresh itself from a disk file while the CPU attends to other tasks.

The asynchronous character of the UNIBUS makes it compatible with devices operating over a wide range of speeds. Because bus-data handling speed is much greater than memory speed, interleaving techniques permit device-to-device data transfers at 2,500,000 words per second, without the need for special multiplexers.

Modular construction allows custom configuring of systems with space left over for easy future expansion. The basic plug-in building blocks, known as System Units, can be mounted in many combinations within the PDP-11. Memory can be expanded by simply plugging in additional modules; the same is true for interface expansion. When maintenance is required, defective System Units can be replaced with

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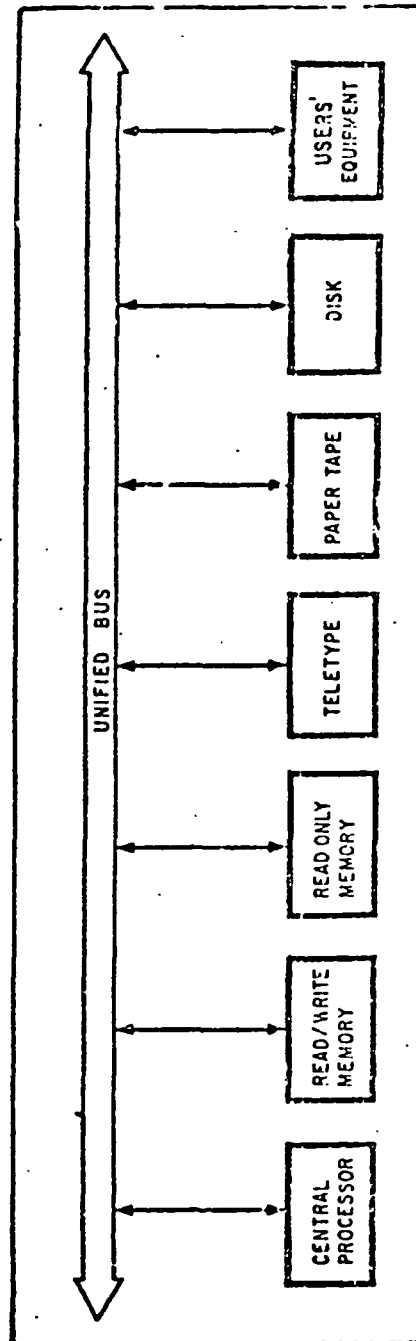


FIGURE 3.2.5-9 UNIFIED BUS

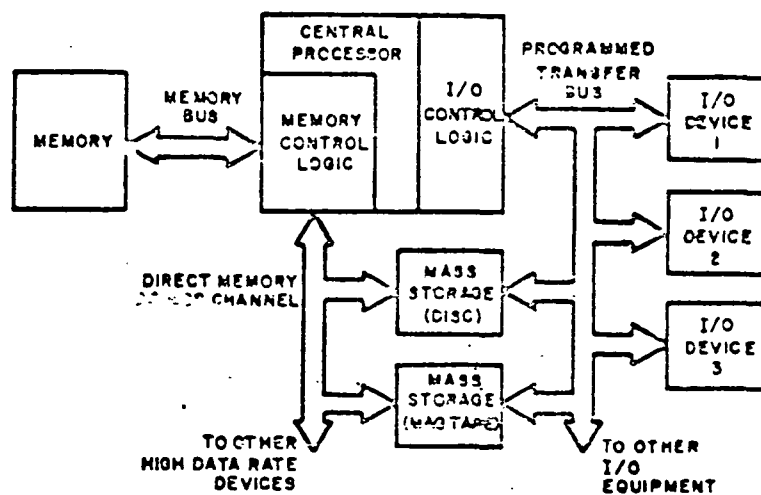


Figure 3.2.5-10 Traditional Computer Architecture

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spares and operation resumed in a matter of minutes. New options can be added as they become available.

Any number of external devices may be attached to the UNIBUS. Standard interfacing modules literally make the addition of peripherals a "plug-in" operation. PDP-11 flexibility lets the user design a system tailored exactly to his needs - from a dedicated, single-computer application to a large, multi-user system. DEC also furnishes a complete line of compatible I/O devices for practically any application.

The PDP-11 can handle many applications that previously were performed by much larger machines. Extensive software and a broad line of peripherals make this possible. Software such as the disk operating system, FORTRAN IV with 1130 FORTRAN features, multi-user BASIC, single-user BASIC, and a real-time operating system provide a wide variety of problem-solving capabilities.

The Disk Operating System aids software development and features a runtime monitor with excellent random access file structure and device independence for flexibility. PDP-11 FORTRAN IV has been designed to simplify software development and can serve as a batch processor system for scientific and data processing applications.

PDP-11 Resource Timesharing System (RSTS) is one of the most powerful versions of BASIC available for multiple simultaneous users. RSTS-11 is ideal for applications in industrial and educational environments.

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The PDP-11 Real-Time Operating (RSC-11C) System is designed to support multi-programming applications in real-time environments such as process control.

Peripherals supported by this software include fixed and moving head disks, industry-compatible magtape, DECtape, card readers, line printers, CRT terminals, industrial process-oriented input/output systems, laboratory input/output systems, and real-time clocks.

Some of the highlights of the characteristics and features of the PDP-11 which makes this computer an excellent choice for the SMS are summarized in Table 3.2.5-2. They are features that were found in such 32-bit computers as the Sigma 5/7 when they were introduced six years ago, but were not found in 16-bit computers of the same generation. Detailed discussions of computer speed, memory, and internal logic as applicable to the application are contained in the following sections.

Future expansion requirements can be met by adding additional CPU's to the PDP-11 system. In addition, faster models of the PDP-11 memory are available which are directly plug-in replaceable with the standard DEC core memory. Should circumstances dictate the need for additional processing speed, a faster memory could be utilized.

On the PDP-11, memories connect directly to the system through the UNIBUS. Because the UNIBUS is asynchronous, there are no timing restrictions to hamper memory selection. Hence, a wide variety of memories having a broad range of speeds and characteristics can be

## Table 3.2.5-2

Characteristics and Features of the PDP 11/45

## EXPANDABLE

As your needs grow, so can your PDP-11

Any unit - including processor, memory, disk, terminals, and other peripheral devices - may be added to the system simply by plugging the unit's controller into the UNIBUS

## UNLIMITED PRODUCT LIFE

Add more processor power or faster memory as required

## EASY TO PROGRAM

Structured data handling is simplified; more efficient instructions; Instruction set has over 400 instructions

## ASYNCHRONOUS DATA BUS

Unique UNIBUS construction eliminates timing programs; makes expansion plug-in simple

## SIXTEEN GENERAL PURPOSE REGISTERS

Greater programming flexibility; registers can serve as accumulators, address pointers, autoincrement or increment pointers and as index registers; eliminates accumulator housekeeping

## HARDWARE STACKS

Previously available only in large-scale computers; stacks (Last-In, First-Out lists) permit reentrant subroutines and automatic nesting of subroutines and interrupts; convenient storage of temporary data; improved speeds and efficiencies.

## BIT/BYTE/WORD/MULTI-WORD HANDLING CAPABILITY

Bits and bytes handled as easily as words; allows dramatic savings in memory. Efficient double- and triple-precision arithmetic capability.

## DIRECT MEMORY-TO-MEMORY AND MEMORY-TO-I/O DEVICE

Operations can be performed between peripherals and memory without accumulators; more efficient I/O - no need for I/O transfer instructions. Peripheral registers are memory locations.

## DIRECT MEMORY ACCESS

Multiple devices can operate simultaneously at maximum DMA rates except for memory access priority delays without tying up the CPM.

## DIRECT DEVICE-TO-DEVICE OPERATIONS

Devices on the UNIBUS communicate directly. Memory has overhead reduced to one-half of that found in conventional equipment resulting in more available processing power.

## EASY INTERFACING

Quicker, easier, and less expensive because of UNIBUS construction and asynchronous operation. A single bus means less interconnections at less cost.

## INTERRUPTS MULTI-LINE

Multi-Line, Multi-Level Automatic Priority Interrupt, + 7 Software Levels.

## OPTIONS

Memory Segmentation, Memories of varying capacities and speeds, Real-Time Clocks, Floating Point Hardware



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freely mixed and interchanged in a single PDP-11 system. All PDP-11 memories are completely self-contained. Each PDP-11 memory contains its own complete data and address buffers and rewrite logic. The CPU can thus begin processing data immediately after accessing it and the memory will rewrite itself while the processor is working. This characteristic makes access time (350 to 500 nano-seconds) the important factor in determining the PDP-11's operating speed. Most computers operate as a function of cycle time, because the CPU must wait until the full memory cycle has been completed.

The only effect of cycle time on the PDP-11 is on those occasions when successive accesses to memory are required. Memory interleave can be utilized to reduce this time significantly (50%) in systems of 8K or more by assigning successive locations to alternating 4K blocks of memory. One block would contain locations 0, 4, 8, 12,..., while the other has addresses 2, 6, 10, 14,... In this manner, transfers to successive locations can be speeded up by overlapping the rewrite in Memory A with the fetch to Memory B as shown in Figure 3.2.5-11.

In the PDP-11, memory interleave is completely transparent to the user, who addresses core as if it were one continuous 8K block. The memories themselves perform the alternation of address assignment. Interleave is available for the PDP-11 at no extra cost.

Direct addressing of up to a total of 32K words of memory and peripheral device registers is included in the standard PDP-11/45.

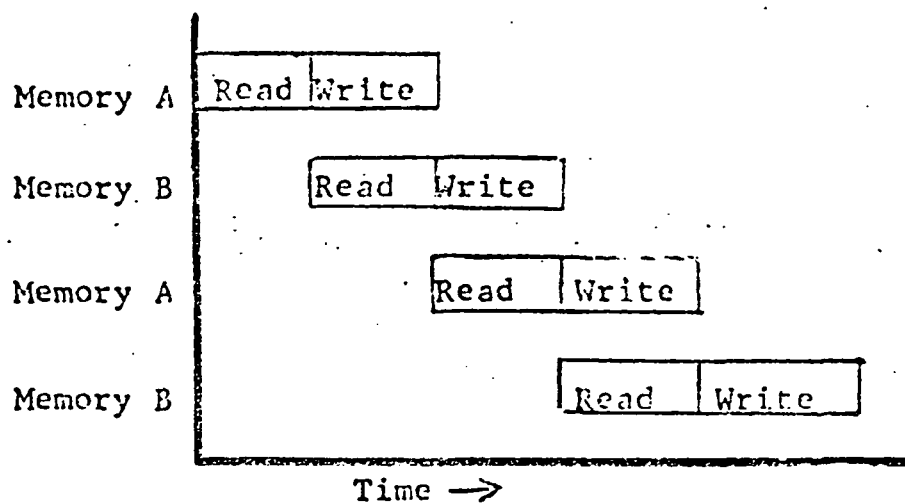
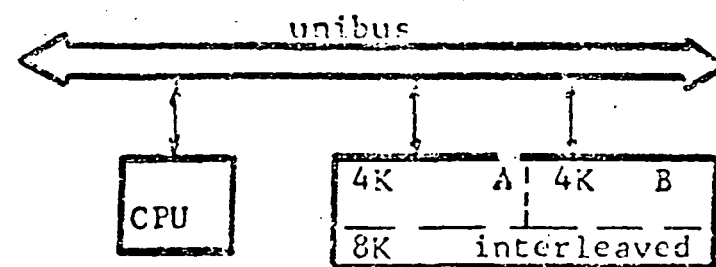


Figure 3.2.5-11 Memory Interleave Timing Program

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Memory segmentation is required to allow a total of 124K 16-bit words of memory to be used in the system. Reference Figure 3.2.5-12 .

There were a number of other machine characteristics besides speed and memory which were determining factors in selecting the computer for the SMS. The features considered most important relate to the flexibility, usability and maintainability of the machine for both in-plant and in-field operation.

Flexibility is important because experience has shown that requirements may change during the course of a program. A computer that may be perfectly adequate for the basic task can become hopeless inadequate as options are added, or new simulation capabilities requested by the user. Therefore it is certainly an advantage to select a computer with features that permit expansion over and above that required by the basic specification.

Ease of use is obviously an important consideration relative to the computers employed on the SMS. A computer that is difficult to program, debug, modify and operate would seriously hamper the initial development effort as well as impact the availability of the trainer during its operational life. Both hardware features and support software affect a computer's usability. A powerful instruction set, a number of general purpose registers, hardware stacks, and byte handling capability are hardware features that make the computer easier to use. Efficient and extensive utility software is essential in order that

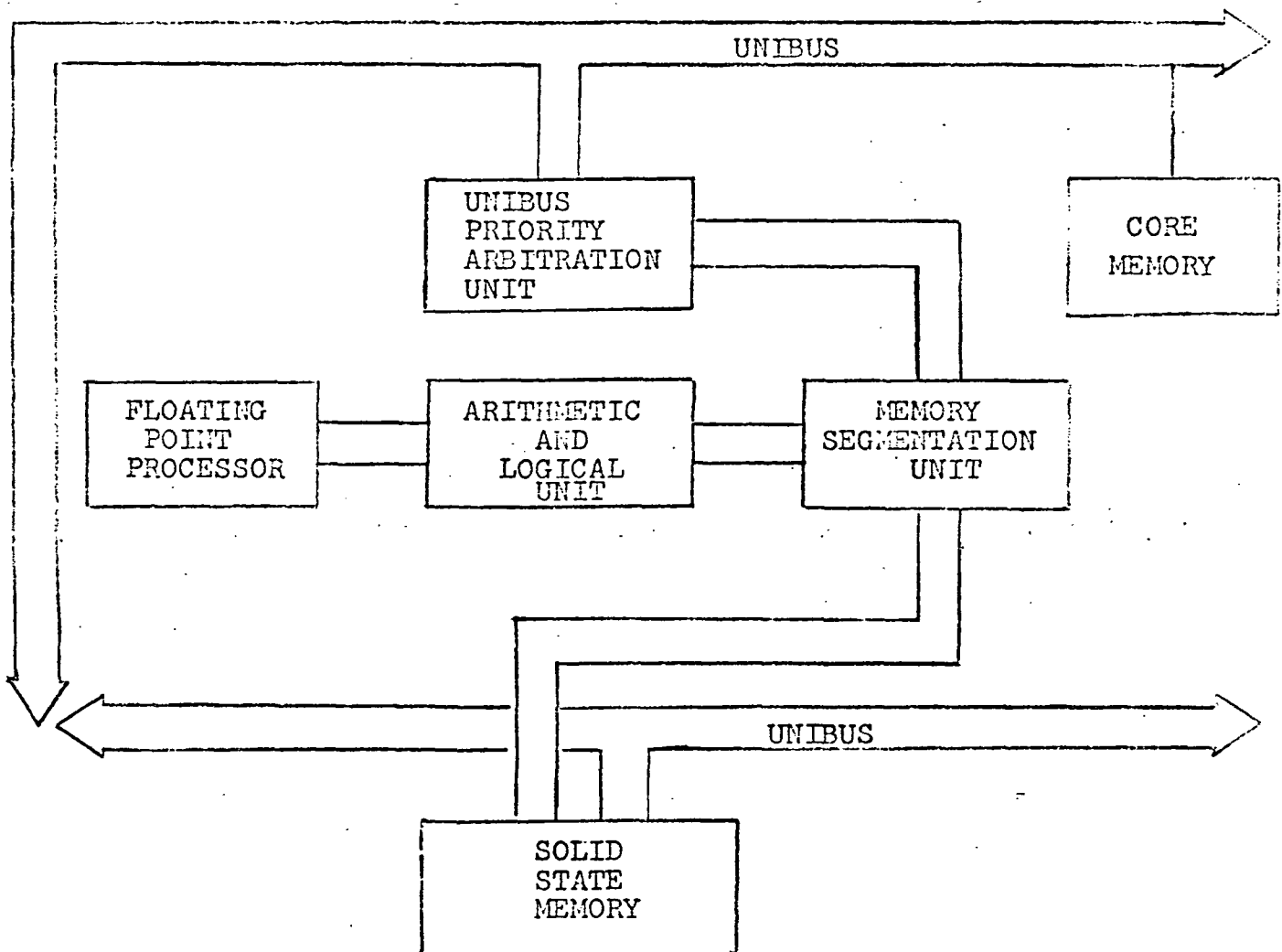


FIGURE 3.2.5-12

PDP 11/45 MEMORY EXTENSION

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programs, once written, can be conveniently assembled, loaded and modified.

Finally, it is important that the computer be easy to maintain in the field as well as in the simulator manufacturer's plant. Features which affect maintainability are the quantity and nature of the diagnostics, the logistics support provided, and the ease with which modules and components can be replaced.

During the industry survey SPD evaluated these features for a number of 16-bit computers and the results are shown in Table 3.2.5-3.

Of the computers surveyed the PDP-11 exhibits adequate speed, the largest memory expansion capability, the greatest flexibility and usability, and maintainability characteristics equal to the best. These conclusions led inevitably to the selection of the PDP-11 as the optimum choice for the SMS.

#### 3.2.5.4.1 Computer Architecture

The PDP-11/45 is a 16-bit parallel-logic machine using two's complement arithmetic which can directly address 32, 768 sixteen-bit words, or 65, 536 eight-bit bytes. Its sixteen general-purpose registers, its versatile instruction repertoire and addressing modes, its stack handling capability, its powerful interrupt logic, and its ability to directly control input/output processing all contribute significantly to the reduction of programming and storage requirements.

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| Feature                             | DEC<br>PDP-11/45  | Varian<br>620f | Honeywell<br>H-316 | XDS<br>Sigma 3 | Raytheon<br>704 |
|-------------------------------------|-------------------|----------------|--------------------|----------------|-----------------|
| Word Length (Bits)                  | 16                | 16             | 16                 | 16             | 16              |
| <u>Hardware Flexibility</u>         |                   |                |                    |                |                 |
| Unified Bus Architecture            | Yes               | No             | No                 | No             | No              |
| Max Memory Expansion                | 124K              | 32K            | 64K                | 64K            | 32K             |
| Memory Increment Size               | 1K, 2K,<br>4K, 8K | 4K             | 4K                 | 8K             | 4K              |
| Various Memory Speeds<br>Available  | Yes               | Yes            | No                 | No             | No              |
| Faster CPU's Available              | Yes               | No             | No                 | No             | No              |
| Multi-CPU Capability                | Yes               | No             | No                 | Yes            | No              |
| Non Cycle Stealing I/O              | Yes               | Special        | No                 | Available      | No              |
| Field Expandability                 | Excellent         | Good           | Good               | Good           | Good            |
| <u>Usability</u>                    |                   |                |                    |                |                 |
| Instruction Set                     | 400               | 141            | 76                 | 37             | 74              |
| Two-Address Inst.                   | Yes               | No             | No                 | No             | No              |
| No. of General Purpose<br>Registers | 8                 | 2              | 2                  | 6              | 1               |
| Byte Handling                       | Yes               | No             | No                 | No             | No              |
| Utility Software                    | Good              | Good           | Good               | Good           | Good            |
| <u>Maintainability</u>              |                   |                |                    |                |                 |
| Latest Circuitry                    | Yes               | Yes            | Yes                | No             | Yes             |
| Module Replacement                  | Excellent         | Fair           | Good               | Good           | Good            |
| Diagnostic Software                 | Good              | Good           | Good               | Good           | Good            |
| Availability of Service             | Good              | Fair           | Good               | Good           | Fair            |

TABLE 3.2.5-3  
COMPARISON OF COMPUTER FEATURES

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The PDP-11/45 is equipped with sixteen general registers. All are program-accessible and can be used as accumulators, pointers to memory locations, or as full-word index registers. The registers are used for general-purpose access such as performing normal computations, saving interim results, and holding often-used data. The fact that all registers may be used as accumulators simplifies the problem of data manipulation between registers. The capability to use all the registers as pointers or index registers greatly simplifies the addressing problem.

Three registers are used as stack pointers and one register is used as a program counter. The capability to address the stack pointers directly allows the pointer to the subroutine calls and returns, the interrupt returns, the stored register values and various other dynamic data which has been saved in the stack to be modified dynamically as required. The capability to address the program counter directly provides the ability to perform immediate, direct, relative, and deferred relative addressing. This is further explained below under addressing modes.

The PDP-11 undoubtedly has the most comprehensive and powerful instruction repertoire and addressing capability of any computer in its class. Its instruction complement illustrated in Figure 3.2.5-13 which includes both word (16-bit) and byte (8-bit) addressing, utilizes the 16 general-purpose registers to provide the programmer with over 400 hardwired instructions while requiring him to learn less than 50

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different operation codes. This is accomplished by providing 8 modes of addressing which affectively creates up to 8 instructions for each basic operation code. In addition, a number of the instructions are double address instructions providing still further capability. The resultant code is highly bit-efficient, and each instruction is capable of accomplishing significantly more operations than is possible in any other computer of this size.

These instructions recognize that most data in a program is structured in some way in a table, in a stack, in a table of addresses or, perhaps as a small set of frequently-used variables local to a limited region of programs. The PDP-11 handles these common data structures with addressing modes specifically designed for each kind of access. In addition, addressing for unstructured data is general enough to permit direct random access to all of core and to permit the writing of directly relocatable code. The PDP-11 addressing modes as indicated in Table 3.2.5-4 include direct register addressing, sequential addressing, full address indexing, and two levels of deferred (indirect) addressing. A brief description and typical use for each mode of addressing is also shown in the table.

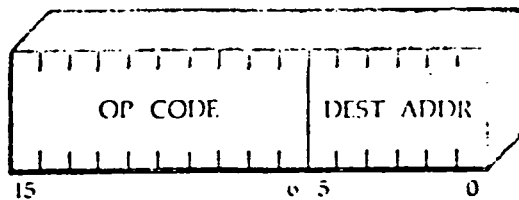
By combining the instruction repertoire with the various addressing modes, extremely powerful instructions may be executed. For example, the instruction

MOV A, B



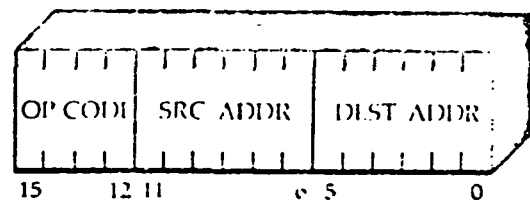
## instructions

## single operand



|         |                               |
|---------|-------------------------------|
| CLR (B) | Clear                         |
| COM (B) | Complement (one's complement) |
| NLG (B) | Negate (two's complement)     |
| INC (B) | Increment                     |
| DEC (B) | Decrement                     |
| ADC (B) | Add carry                     |
| SBC (B) | Subtract carry                |
| TST (B) | Test (Set condition codes)    |
| ROR (B) | Rotate right                  |
| ROL (B) | Rotate left                   |
| ASR (B) | Arithmetic shift right        |
| ASL (B) | Arithmetic shift left         |
| SWAB    | Swap bytes                    |

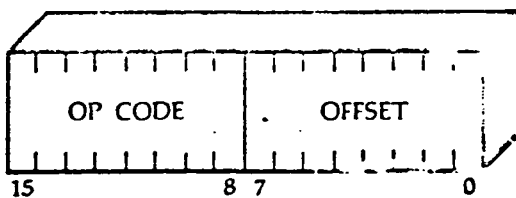
## double operand



|         |           |
|---------|-----------|
| MOV (B) | Move      |
| ADD     | Add       |
| SUB     | Subtract  |
| CMP (B) | Compare   |
| BIT (B) | Bit test  |
| BIC (B) | Bit clear |
| BIS (B) | Bit set   |

} Boolean Functions

## branch instructions



Offset allows a branch ahead of +128 words, and back -127 words.

| INSTRUCTION | BRANCH CONDITION      |
|-------------|-----------------------|
| BR          | Always                |
| BEQ         | Equal or zero         |
| BNE         | Not equal             |
| BNM         | Minus                 |
| BPL         | Plus                  |
| BCS         | Carry set             |
| RCC         | Carry clear           |
| BVS         | Overflow set          |
| BVC         | Overflow clear        |
| BLT         | Less than             |
| BGE         | Greater than or equal |
| BLE         | Less than or equal    |
| BGT         | Greater than          |
| BHI         | Higher than           |
| BLOS        | Lower or same         |
| BHIS        | Higher or same        |
| BLO         | Lower                 |

## control instructions

|     |                        |
|-----|------------------------|
| JMP | Jump                   |
| JSR | Jump to subroutine     |
| RTS | Return from subroutine |
| RTI | Return from interrupt  |

## condition code operator

|            |                    |
|------------|--------------------|
| SET C.VN.Z | Set selected bit   |
| CLP C.VN.Z | Clear selected bit |

## miscellaneous instruction

|       |                       |
|-------|-----------------------|
| HALT  | Stop processor        |
| WAIT  | Wait for interrupt    |
| RESET | Initialize the system |

## traps

|      |                          |
|------|--------------------------|
| NOT  | IOX call                 |
| INT  | Emulate call             |
| TRAP | User defined instruction |

FIGURE 3.2.5-13 PDP-11 INSTRUCTION COMPLEMENT

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| DIRECT ADDRESSING MODES   |      |   |                   |   |  |
|---------------------------|------|---|-------------------|---|--|
| SYNTAX                    | MODE | @ | FUNCTION          | DESCRIPTION   | TYPICAL USE                            |
| $R_n$                     | 00   | 0 | Register          | General register direct addressing. The operand is in the register.   | Use register as accumulator.           |
| $(R_n) +$                 | 01   | 0 | Auto Increment    | The address of the operand is taken from the register and then the contents of the register are incremented.  | Pointer to sequential data.            |
| $-(R_n)$                  | 10   | 0 | Auto Increment    | The contents of the register are decremented. The register then contains the operand address.   | Useful for stack operations.           |
| $A(R_n)$                  | 11   | 0 | Index             | Register is used as index register. The effective address is the sum of A and the specified register.   | Random access to elements of a table.  |
| DEFERRED ADDRESSING MODES |      |   |                   |   |  |
| $@R_n$ or $(R_n)$         | 00   | 1 | Register Deferred | Deferred register addressing. The location of the operand is in the register.   | Register holds address.                |
| $ @(R_n) +$               | 01   | 1 | Auto Inc Deferred | The address of the location which contains the effective address of the operand is taken from the register and then the contents of the register are incremented. | Point to table of addresses.           |
| $@-(R_n)$                 | 10   | 1 | Auto Dec Deferred | The contents of the register are decremented. The register then contains the address of the location which contains the effective address of the operand.         | Stack operations on addresses.         |
| $@A(R_n)$                 | 11   | 1 | Index Deferred    | Deferred indexing causes the effective address to be the sum of the contents of the location specified by A, and the contents of the specified register.          | Random access in a table of addresses. |

TABLE 3.2.5-4 PDP-11 ADDRESSING MODES

|              |  |                   |
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incorporates, in one statement, the operation of moving the contents of location A to location B. Locations A and B may be any combination of high-speed registers, memory locations, or device registers on the UNIBUS. Addresses A and B are full 16-bit addresses allowing the programmer complete freedom to address the full range of the machine which in this case is 32K words or 65K bytes.

As another example of the PDP-11's code efficiency, any two addressable locations may be added together and the result placed in the destination location using the following command without load accumulator and store accumulator instructions.

ADD A, B

With the ADD instructions, a programmer can:

- 1) Add two general registers;
- 2) Add the contents of a core location to a general register;
- 3) Add the contents of a general register to a core location;
- 4) Add the contents of one core location directly to the contents of a second core location.

Note that in the last case, no general register was needed to form the sum of the two numbers. This is possible because any core location in the PDP-11 can be used as an accumulator. Additional program simplifications may be made by using the computer condition codes. Four bits of the program status word are assigned to monitoring different results of previous instructions. These bits are set as follows:

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A - if the result was zero.

N - if the result was negative.

C - if the operation resulted in a carry from the  
most significant bit.

V - if the operation resulted in a arithmetic overflow.

A branch on condition instruction is used to sense the  
status of these bits and transfer if the condition is met.

Recognizing that the program counter is also a general  
register and that each of the possible addressing modes may be applied,  
several important functions are available which greatly simplify the  
programming task and save considerable memory:

1) Immediate addressing provides time and space improve-  
ment for access of constant operands by including the constant in the  
instruction. The instruction word referencing an immediate operand  
specifies auto increment addressing through the program counter.

$(R_7) +$

The program counter points to the word after the  
instruction word following the instruction fetch. The contents of this  
word are therefore used as the operand and the program counter is ad-  
vanced to the next word. The PAL-11 assembler recognizes address  
expressions of the form "#n" as immediate operands and codes them with  
the proper address field followed by the word of data.

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2) Absolute addressing allows the contents of the location following the instruction word to be taken as the address of an operand by specifying deferral in immediate mode addressing.

@ (R<sub>7</sub>) +

Instructions with an address of the form "#A" refer to the operand at address A.

3) Relative addressing specifies an operand address by using the program counter as a base register and at assembly time calculating an offset which is stored in the index word of the instruction. The instruction is of the form OPR A(R<sub>7</sub>) followed by the index word. The assembler operates on the instruction in the form OPR A.

4) Deferred relative addressing permits access of data through memory locations holding operand addresses. This addressing mode is of the form @A(R<sub>7</sub>) and is operated on by the assembler in the form OPR@A.

The PDP-11 central processor has special last-in, first-out "Stack" handling capability. Words may be "pushed" onto a stack or "popped" off a stack with simple instructions. All general registers may be used to maintain a stack pointer. Register 6 is used by the Central Processor Unit (CPU) to maintain a special processor stack. Subroutine calls automatically save and restore on this processor stack the register used as the linkage pointer in the call. The CPU interrupt process automatically stacks the current program counter and the central

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processor status word holding the processor priority and other CPU status information. These are restored upon the return from the interrupt service routine. Subroutines and interrupts are, therefore, automatically nested by the central processor hardware, conveniently enabling subroutine calls within subroutines or interrupts without complex software.

Both the interrupt handling hardware and the subroutine call hardware are designed to facilitate writing reentrant code for the PDP-11. This type of code allows use of a single copy of a given subroutine or program to be shared by more than one process or task. This reduces the amount of core needed for real-time applications such as the concurrent servicing of many peripheral devices.

The central processor recognizes up to four levels of hardware interrupt from external devices. Many devices may be attached on each level with the device closest to the central processor given priority over the other devices on the same level. The hardware interrupt priority levels are interleaved by programmable central processor priority levels, thus allowing the running program to select the priority of allowable interrupts. Additional speed and power are added to the interrupt structure through the use of the PDP-11 full-vectored interrupt scheme. With the vectored interrupts, a unique interrupt service routine is automatically selected by each device without device polling via software. The device's interrupt priority and service routine priority are independent. This allows dynamic adjustment of system be-

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havior in response to real-time conditions.

The CPU also recognizes several internal interrupts which are very useful during system debugging. A reserve instruction trap is caused by attempt to execute an instruction reserved for future expansion (i.e., non-existent). A stack overflow trap is caused by reference addresses below address 400) through the processor stack pointer R6 in auto increment or auto decrement deferred addressing. Attempts to reference word operands at odd addresses will cause a bus trap as will no response from an addressed device. A power failure will cause a trap as will restoration of power (for auto restart). If the T bit in the program status word is set when an instruction is fetched from memory, a processor trap will be caused by the completion of the instruction's execution. This feature is used during program debugging and can be set or cleared under program control.

Programming of peripherals is extremely simple in the PDP-11. A special class of instructions to deal with input/output operations is unnecessary. The UNIBUS permits a unified addressing structure in which control, status, and data registers for peripheral devices are directly addressed as memory locations. Therefore all operations on these registers, such as transferring information into or out of them or manipulating data within them, are performed by normal memory reference instructions.

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The ability to use all memory reference instructions on peripheral device registers greatly increases the flexibility of input/output programming. Information in a device register can be compared directly with a value and a branch made on the result.

CMP #101, PRB

BEQ SERVICE

In this case the program looks for  $101)_8$  from the paper tape reader data buffer, and branches if it finds it. There is no need to transfer the information into an intermediate register for comparison.

When the character is of interest, a memory reference instruction can transfer the character into a user buffer in core or into another peripheral device.

MOV PRB, LOC

This instruction transfers a character from the paper tape reader buffer into a user-defined location.

All arithmetic operations can be performed on a peripheral device register.

ADD #10, DSX

This instruction will add  $10)_8$  to a display's X deflection register.

All peripheral device registers can be treated as accumulators. There is no need to funnel all data transfers, arithmetic



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operations, and comparisons through a single or small number of accumulators.

The PDP-11 Real-Time Clock provided in the SMS mini computers can be program-selected to clock at one of four frequencies:

- 1) 100 KHz crystal-controlled
- 2) 10 KHz crystal-controlled
- 3) External analog signal
- 4) Line frequency: 50 or 60 Hz.

The program loads an internal count into a 16-bit count register in the programmable clock. This register counts toward zero at the preselected count rate. When the counter reaches zero an interrupt is generated. The value of the clock register may be read at any time to determine the elapsed time.

The clock has three program-selectable modes of operation:

Single-Interrupt Mode - When the internal count goes to zero, the clock stops and generates an interrupt. This mode is useful at the end of the timing interval. This eliminates the need to count timing signals under program control.

Repeat-Interrupt Mode - The internal count is stored in a count set buffer and will automatically reset the counter when the count goes to zero. This allows repeated interrupts at program-specified intervals without any time loss. Time is maintained at crystal accuracy.

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External-Event Counter - The internal count may be loaded and an interrupt generated after a specified number of events - such as an external timing source. A counter may also start at zero and be read by the program to determine the number of events that have occurred.

#### 3.2.5.4.2 SMS Mini Computer I/O Processor Baseline Configuration

The PDP/11-45 Mini Computer will be used in the SMS for Interface, I/O control, and data processing functions for the D.C.E. and on-board computer simulations.

Figure 3.2.5-14 is a block diagram of the MECS and FBSC systems with associated peripheral equipment. As indicated, a total of seven PDP 11/45 computers will be provided.

Peripherals include DEC Writer Terminals, Dick.. Memories, a Card Reader, a Line Printer, DEC Tape Unit, and a High Speed Paper tape reader/punch. The PDP-11 configuration for the SMS was selected to provide the most flexibility for growth and change as awareness of the true problem grows during evaluation. Towards this end the computer system includes the following features:

#### A) PDP-11/45 Central Processors with Floating Point Hardware

The PDP 11/45 Floating-Point Hardware option will allow efficient Fortran programs to be used for the basic math models. Such flexibility is imperative in any experimental simulator system.

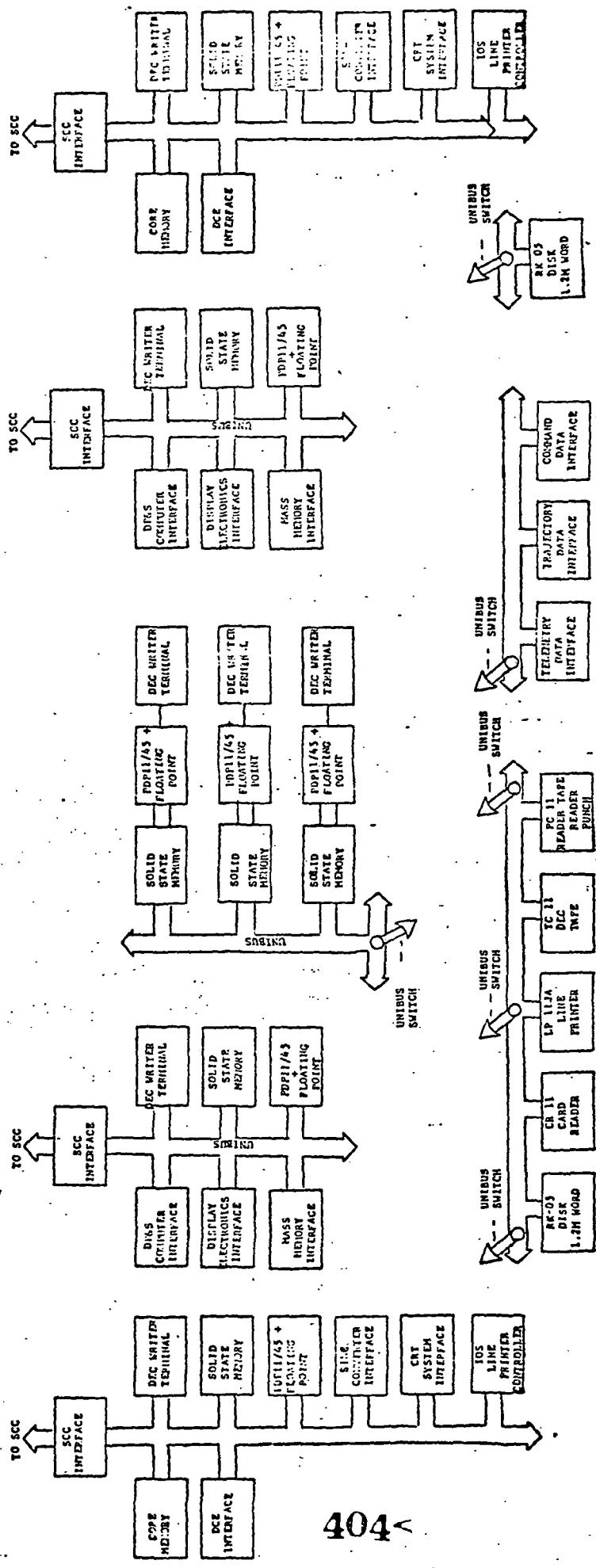


FIGURE 3.2.5-14  
BLOCK DIAGRAM  
SPS MINICHAMBER CONTROL

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## B) Memory

Three types of memory are available for the PDP-11/45.

### Solid State:

Bipolar memory with a cycle time of 300 msec.

MOS Memory with a cycle time of 450 msec.

### Core:

Magnetic core memory with a cycle time of 850 msec.

Each computer system can be expanded from the basic 4096 words to 126,976 words in increments of 4096 words. Each system can also be configured with various mixtures of the three types of memory, with a maximum limit of 32,768 words of Solid State Memory.

Multi-processor systems depend on rapid communication between processors. In a dedicated-subprocessory system, data prepared by one processor must be passed quickly to the processor that will work on it next. In a general system, both programs and data must be passed quickly from master processor to job processor for execution.

Dual-port memory provides the required communications speed by making the same memory accessible to two separate processors. Information stored in memory by one processor is immediately accessible to the other. There is no need to load the information into one processor's memory and then physically move it to a second processor's memory. Shared memory also allows two processors to execute the same

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program without having to maintain their own copies of it in their own memories. The ability to share both programs and data reduces the total memory required for a multiprocessor system.

The dual-port, solid-state memories of the PDP-11/45 and PDP-11/50 provide this shared-memory capability. Two processors can request access to the shared memory independently and simultaneously. Any timing conflicts are automatically arbitrated on a priority-basis. When used on conjunction with the Memory Management Option (KT11-C), the shared memory also provides independent read-and write protection checking for both of the two processors.

The SMS system PDP-11 computers will include combinations of MOS Memory and Core Memory as indicated in the block diagram to obtain an optimum match to meet computer speed requirements and remain cost effective.

### C) The Unibus Window

The Unibus Window extends the concept of dual-port memory by allowing memories to be made shareable or non-shareable dynamically and on-line, and by allowing the control of peripherals to be shared, as well. The Unibus Window allows each of two processors to have shared access to part of the other processor's memory. Each processor selects the part of the other processor's memory it wishes to access, on either a read/write or read-only basis. The Window then establishes the proper connections between busses so that subsequent memory references are handled on a completely transparent basis. Since all peripheral control registers also have addresses associated with them, selecting the last 4K words of the other processor's address space permits complete peripheral sharing, as well.

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#### D) The Unibus Switch

Redundancy and modularity are both achieved on PDP-11 systems by means of DT03-F UNIBUS switches that allow individual system components or groups of components, to be switched in or out of the operational system, or switched from one processor to another as shown in Figure 3.2.5-14A & B. These bus switches, which are engineered for extremely high reliability themselves, allow components to be switched automatically or manually. By configuring networks of switches, any desired degree of redundancy and modularity can be achieved.

Because it is a bus switch rather than a controller or interface switch, the PDP-11 UNIBUS switch allows any combination of peripherals and memories to be switches. The same switch handles mass-storage devices, magnetic-tape drives, process-control devices, special-purpose interfaces, and even memory. Since the switched busses are standard UNIBUS types, any combination of devices can be connected to them, each with a standard device controller.

Unibus switches will be provided in the SMS mini computer complex to allow sharing of peripheral equipment.

#### E) Mass Storage

The system will have two 1.2-megaword moving head disks, for a total mass storage of 2.4 megawords. Both disks will be provided with the MBCS, and will be shared when the FBSCS is added to the system. Two disks are preferable to one of larger capacity, and this will provide the capability to edit and copy disk packs. Removable disk cartridges are preferable to

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fixed disks, and this will permit the capability to switch between alternate data or program configurations merely by switching disk packs and not by reloading from tape. Under the timing requirements of the program, the slightly longer access time (.06 seconds/average) will not pose any problem, and be more than offset by the advantages. The disks will contain the real-time programs for rapid startup, and will contain overlays of the IOS CRT Data Processing Programs.

F) Line Printer

The line printer will be the DEC LP-11 unit. This is a 132-column, 64-character-set printer, with a maximum print rate of 1100 lines per minute, and a nominal speed of 450 lpm. It will provide summary listings for evaluations.

G) Card Reader

The DEC CR11 300-cpm card reader will be provided. It will be available for program and data maintenance.

H) Data Terminal

Each PDP 11/45 computer in the SMS complex will be provided with an LA30 DEC writer terminal. The DEC writer is a fast, reliable and low cost data terminal. It prints from a set of 64 characters at speeds up to 30 characters per second. Data entry is made from either a 97 or 128 character keyboard. It produces an original and one copy on standard 9-7/8 inch wide tractor driven continuous form.

I) A dual unit DEC tape bidirectional magnetic tape transport system will be provided for auxiliary data storage.



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The DEC tape system consists of the TC11 control, TU56 Dual Transport, which will buffer and control information for up to four TU56 dual transports, and DEC tape 3/4 inch magnetic tape on 3.9 inch reels.

J) High Speed Reader Punch

A High Speed Paper Tape Reader Punch will be provided. This unit is capable of reading eight-hole un-oiled perforated paper tape at 300 characters per second and punching tape at 50 characters per second. The subsystem consists of a High Speed Reader/Punch and the PC11 Control.

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#### 3.2.5.4.2.1 Mini Computer Software Organization

The architecture of the PDP-11/45 computer lends itself extremely well to structuring the SMS programs in a modular fashion. The CPU has three basic modes with a predetermined hierarchy called the Kernal mode, the Supervisor Mode, and the User Mode. The Kernal mode is intended to be the heart of the executive system. The Kernal mode allows certain restricted instructions to be executed, and by proper design of the software, numerous restrictions and/or protections can be imposed upon or provided for the supervisor and user routines. In the Supervisor mode, the Supervisor mode segmentation registers will be used by the on line utility system to allow access to the user instructions and data presently logged in at the TTY or the CRT. The Kernal mode will use the Kernal mode segmentation registers to service the hardware and to provide sequencing and protection to the various user routines.

The memory segmentation unit also has the capability of distinguishing between instruction fetches and data accesses by separating the instructions from the data when coding the routines. It is possible to use the segmentation unit to distinguish between instruction fetches and data accesses thus providing a total of 64000 word addresses, 32000 of which may be used for instructions and 32000 may be used for data. All 32,000 instructions may be executed and all 32,000 data words may be accessed without reconfiguring memory

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via the segmentation registers. This is a significant advantage on large systems where the data pools are large and there is a possibility of design to execute large routines. Without this separation of instructions and data and the additional addresses provided, it would be necessary to divide the data words into a number of small blocks and the desired block to be accessed must be determined under software control.

#### 3.2.5.4.2.1.1 Mini Computer Executive Program

The basic purpose of the Monitor/Executive program in conjunction with the Master Control program will be to cycle the various SMS system programs in a specific order and at the correct time. In doing so, the monitor will be able to handle any and all interrupts associated with the real-time clock, and the I/O devices such as the moving-head disc, the DCE devices and the CRT Display systems. Additionally, during the verification and/or update phases, the monitor provides the user with error-handling routines to identify programs in error; and, timing routines to indicate program, frame, and cycle times.

The Monitor/Executive program - in addition to handling the scheduling of the various routines - also contains the real-time monitoring function, Power Fail/Restart, and the real-time input/output functions. The Power Fail/Restart function for the proposed device will ensure the safe shutdown of the equipment upon sensing of a power failure. This includes the safe-store of all volatile registers and

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clean up of I/O in progress (i.e., stopping disk transfer, etc.). Upon sensing a power failure, the program counter and program status registers are stored in the stack and program control is transferred to the power fail subroutine. This subroutine will safely store the volatile registers and half the program. After power is returned to the system the routine sends out a system reset to ensure that all I/O devices are placed in the ready state. Next, the routine establishes the data paths which were terminated. At the end of this process the volatile registers are restored and the program control is returned to the interrupted routine. The program resumes execution at that point. This approach maintains the integrity of the system and permits an auto restart following return of power.

The real-time monitoring function of the executive program provides a means of determining the average execution times of each real-time subroutine module and the worst case execution time of the programs. This is accomplished through the use of the programmable real-time clock system and the T-bit of the central processor status register. The T-bit is set at the beginning of the routine. When the jump to the routine is executed, an interrupt occurs, at which time an interrupt processor will read the real-time clock counter and store this value. The routine is then executed and at the completion the T-bit is again set, causing another interrupt. The real-time clock is then interrogated and the time difference is calculated. This time

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is added to the averaging values and is compared against the worst case time to determine if the value is the worst case yet encountered or if the value can be ignored. By operator request these values may be listed to give a time history of the run times required by the subject routine or program.

The real-time input/output operation of the SMS is based on an interrupt-and-demand request function. This routine services the teletype, display system communication, disk unit, the trainer linkage, and the tape recorder. The linkage system works entirely through the interrupt processor asynchronously to the program. At the beginning of each 50-millisecond period the servicing of the real-time I/O is begun. At the completion of each function (such as analog inputs), an interrupt is generated and the interrupt processor will initiate the discrete input functions. Following the appropriate interrupts, the analog and discrete outputs will be serviced. At the completion of these functions the system waits for the next minor cycle to reservice the system I/O.

The executive will be based on a time frame reference cycle of 1.0 seconds. This reference cycle will be referred to as the major cycle. During this period all of the real-time programs will have been serviced at least once. To accommodate the need for high iteration rate for the CRT system associated input/output, the time frame for the minor cycle will be 25 milliseconds. During this cycle time various

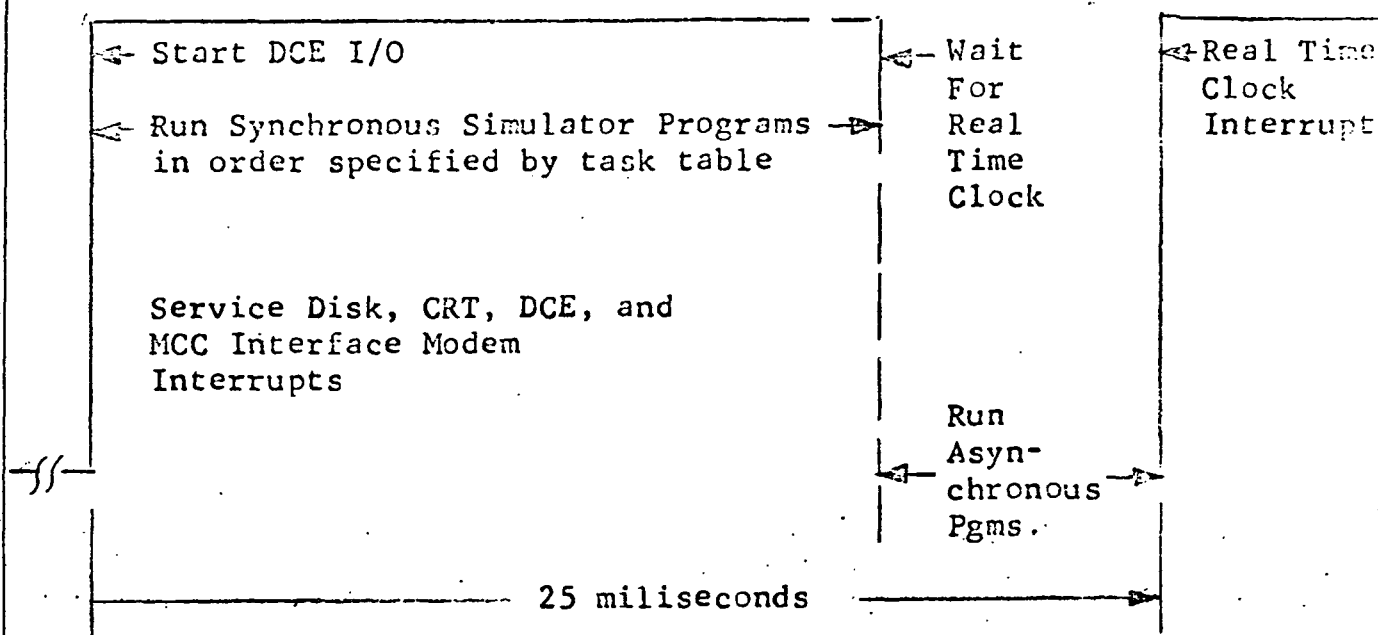
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system routines (e.g., CRT I/O) will be exercised. The particular minor cycle in which a routine will be called will be a function of both the repetition rate and the loading that the routine will place on the time available. By proper choice of the minor cycle into which each of the various routines are placed, the time-loading will be spread evenly throughout the major cycle. The method used to call the routine is a Jump to Subroutine (JSR) using the stack processor. This instruction permits rapid calling of the routine and permits the stacking of calls such that as the program threads through various levels of routines, the returns are automatically stored and as each level of processing is completed the routine will exit, automatically reducing the cue length. The use of the stack processor eliminates the need of multilevel routines to maintain a safe store of the program linkage and a rapid transfer of control from one routine to another.

The monitor, in order to accomplish its prime task of cycling simulation programs, makes use of two features of the PDP 11/45; namely, interrupt structure and segmentation. The PDP 11/45 interrupt structure allows one monitor to service interrupts as they occur and yet to maintain synchronism by using a real-time clock interrupt to dictate the start of each minor cycle. The PDP 11/45 segmentation feature, allows the monitor to enable only that part of core required by the simulation program that is cycling at a given instant, thus providing protection to other simulation programs, while allowing loads

larger than would normally be possible.

As can be seen in the diagram below, the monitor cycles each frame when signaled by the real-time clock interrupt.



The DCE, which actually consists of six separate transfers is always started with the reception of the real-time clock interrupt. As each transfer is completed, an interrupt is generated and the next transfer is initiated. By allowing the DCE interrupt service routine to run at a level higher than the synchronous simulation programs, complete servicing of the linkage is assured each cycle with a minimum of overhead.

Figure 3.2.5-15 depicts the PDP 11/45 interrupt structure and at what levels the various devices are serviced and the various programs are run within the monitor.

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As can be seen in Figure 3.2.5-15, not only is the real-time clock capable of interrupting any simulator program, but, all I/O devices are run at a higher level than the programs and therefore are also capable of interrupting any program. This structure ensures that asynchronous I/O devices will be serviced as required without the loss of data and with a minimum of interference to the synchronous simulation programs.

Because some simulation programs are more critical to the generation of true-to-life responses, the monitor provides program execution at two CPU levels and while it is possible to call synchronous or asynchronous programs at either level, the present monitor contains the code to cycle synchronous simulation programs at CPU level 3. Levels 2, 1, and 0 are used for asynchronous programs, message outputs, and non-critical debugging routines.



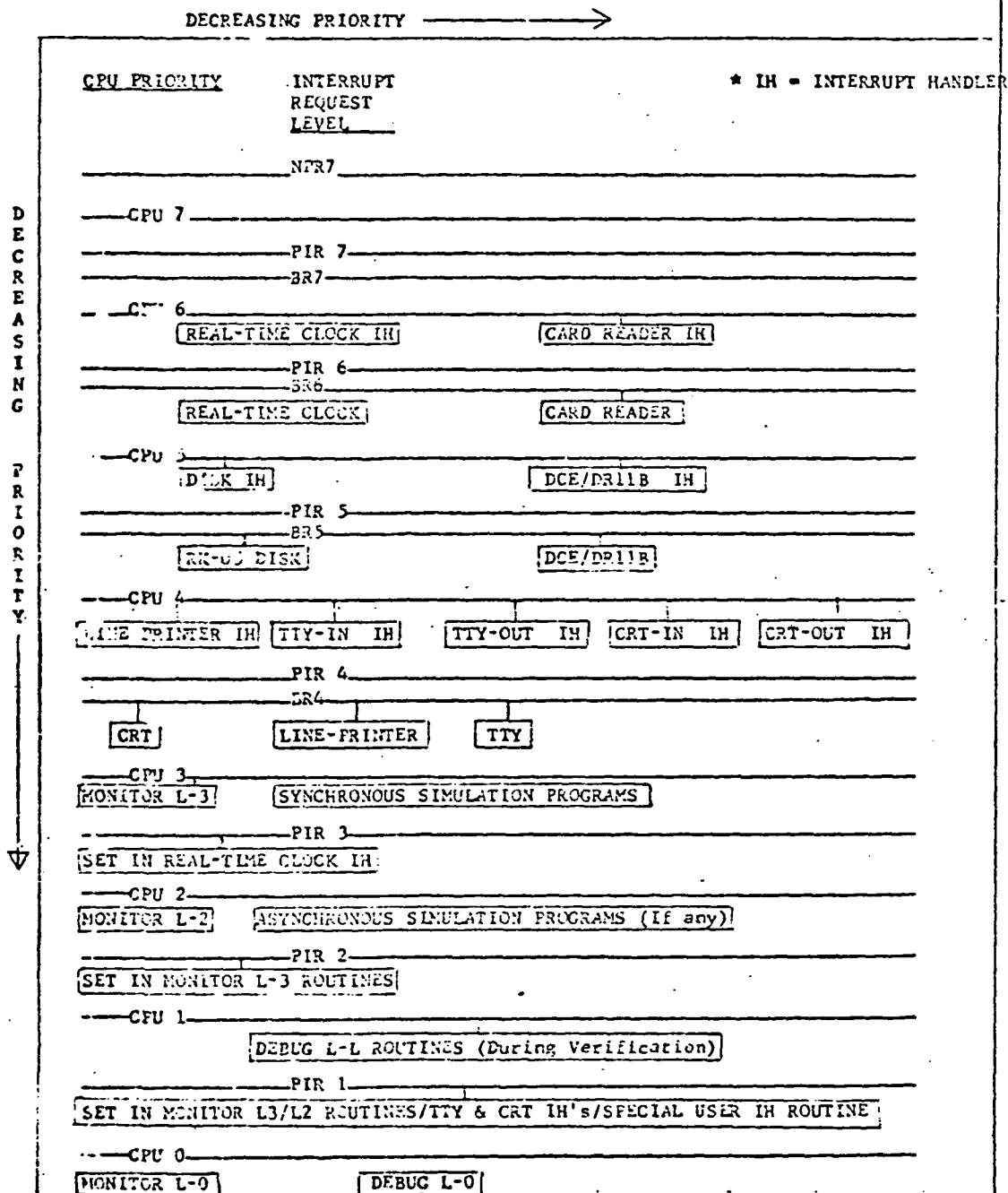


FIGURE 3.2.5-15 PRIORITY STRUCTURE

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### 3.2.6.2 DCE Configurations

At the present time nearly all simulation applications utilize a centralized DCE system of one form or another. Until recently, it has been impractical to segment sections of DCE equipment due to physical size and weight limitations of equipment packaging especially where these electronic assemblies have an adverse effect on the usable payload capabilities of motion systems. The centralized DCE system has utilized the highest packaging efficiency practical. This is due primarily to the following:

1. DCE has been supplied by Computer Manufacturers who, having had no specific knowledge of the simulator application, have packaged their equipment in their classical manner and in a highly modular form.

2. Where simulator manufacturers have designed their own systems, the modular approach has been adhered to principally to minimize costs for large numbers of like devices.

With the rapidly expanding availability of specialized LSI and MSI circuitry and analog to digital and digital to analog converter modules, a great wealth of "Bits and Pieces" hardware exists for structuring DCE systems. It is true, however, that the user has been left largely to his own initiative to design, configure and build systems from this hardware. Therefore, Distributed DCE systems have existed mainly as special purpose configurations in particular applications.

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In the area of simulation, Distributed DCE has been mainly the result of the simulator manufacturer's efforts to improve performance and reduce system costs while still maintaining some degree of flexibility. Therefore, the simulator complex configuration has dictated the degree of modularity since a simulator is made up of physically separable sections as indicated in Table 3.2.6-1.

I/O Device types and quantities attributable to each section change radically in going from one type aircraft or spacecraft to another. Also, the I/O Device types and quantities are a function of the Basic Motion and Visual systems anticipated to be used.

#### 3.2.6.2.1 Centralized DCE

In the broadest sense, the technique of centralized DCE is based primarily on a packaging scheme and only indirectly results in the addition or omission of electronic hardware because of the packaging methodology. A centralized DCE system consists of all the necessary electronic hardware (A/D's, D/A's, DI's, DO's, control and steering logic, etc.) housed in one or more equipment cabinets in close proximity to each other and generally also in close proximity to the simulator's computer complex.

Other characteristics of the centralized DCE are as follows:

1. Requires a comparatively simple and efficient method of obtaining and distributing DC power.
2. Permits single point maintenance for all sections of the DCE.

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### 3.2.6 Data Conversion Equipment

Data Conversion Equipment (DCE) is defined as equipment required for conversion and formatting of analog and digital signals input to and output from the digital computation system to/from the remaining portions of the SMS. In this context, it includes the main host computer interface equipment plus Analog/Digital, Digital/Analog, Discrete Digital Signal Input and Discrete Digital Signal Output conversion equipment and specialized conversion hardware such as Electronics Synchro Resolver Drivers.

#### 3.2.6.1 Computer - DCE Interface

The available techniques for achieving a satisfactory computer interface with a large Digital Conversion System are limited. To a very great extent, the actual hardware interface is dependent on the design of the computer and its interface options. Most DCE system designs are tailored to satisfy the requirements of the particular computer chosen. Because of the simulation requirement to transfer large numbers of digital words per unit time, both into and out of CPU core memory, the established practical norm has become a Bit Parallel, Word Serial Format.

### 3.2.6.1.1 DMA, Data Block Transfers Under Real Time I/O Program Control

This technique permits data transfer via direct memory access from an I/O controller in the main computer or by use of a separate Satellite processor. The I/O Program controls device type (D/A, A/D, DI, DO) selected, and basic update rate. A DMA controller contains registers used to:

- a. Store the word count for each block transfer
- b. Store DCE status and commands
- c. Store input and/or output data

The I/O Program then commands a particular transfer operation of X words (or Bytes) to or from a specified starting core location, for a particular DCE device type. The command is implemented as follows:

- a. The number of words to be transferred are stored in the Word counter of the DMA Device Controller.
- b. The DMA Device Controller, independent of the CPU I/O Controller but in a priority, cycle stealing architecture, then commences the sequential word transfer to or from the starting core location and decrements its word counter until the block transfer is completed. Each transfer is carried out via a hand shaking operation between the Device Controller and the DCE System Controller. This assures the necessary control and synchronization between the two devices, which generally have completely independent clocks.

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3. Avoids the necessity of hardware and driver/receiver electronics to distribute high-frequency Digital Data and Control signals around the simulator complex over long lines and also avoids the use of electronic logic required to multiplex and demultiplex the data transferred in bit parallel, word serial format.

4. Simplifies the addition of such optional DCE features as closed-loop self-test since all the DCE Equipment inputs and outputs are centrally located for ease of accessibility.

5. Location in close proximity to the computer complex minimizes the payload required to be carried on the Motion System for DCE related to devices in the trainer areas.

6. Requires the least number of packaging designs and hardware variations.

7. Requires long cable runs to the trainer electronics assemblies with consequent analog noise susceptibility problem considerations.

8. Requires several cabinets worth of floor space in the trainer floor plan.

There are almost continuous opportunities to reduce the total volume and cost of any given DCE System with the development of new LSI/MSI Electronics and related packaging schemes. The limiting element here, however, is the efficiency with which I/O Signal cabling and cable distribution can be integrated into electronic packaging designs.

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Presently, the cost of small modular D/A converters has been reduced to the level where it is economically feasible to design and build a DCE analog output subsystem having a dedicated converter and buffer register for each channel.

Virtually all simulation DCE equipment produced to date tends toward the centralized DCE technique. A minor variation to this is the placement of some particular quantity of DCE hardware located physically closer to the using devices. (This technique is used on some of Singer Co.'s large commercial simulators, namely, the 747's and L-1011's where some DI and DO P/C card gates are located in the cockpit atop the 60-inch stroke, synergistic motion system.

More recently, Singer-SPD has developed and produced a Centralized DCE System being used on its current 727 and C-130 Simulators known as the "T-Linkage". A significant cost reduction was realized along with reduction in system volume through the use of wire-wrapped, DIP Socket back-plane gates for the entire digital and control portion of the DCE system, thus eliminating all printed circuit cards from that section. Logistical support problems were consequently reduced since the most probable item requiring replacement has now become the IC itself. A block diagram of the system is shown in Figure 3.2.6-1.

The system can be configured as follows:

- a. DI: Modules of 8 16-bit words expandable to a total of 224 words.

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(May be TTL or 28 V DI's chosen in Blocks of 8 words.)

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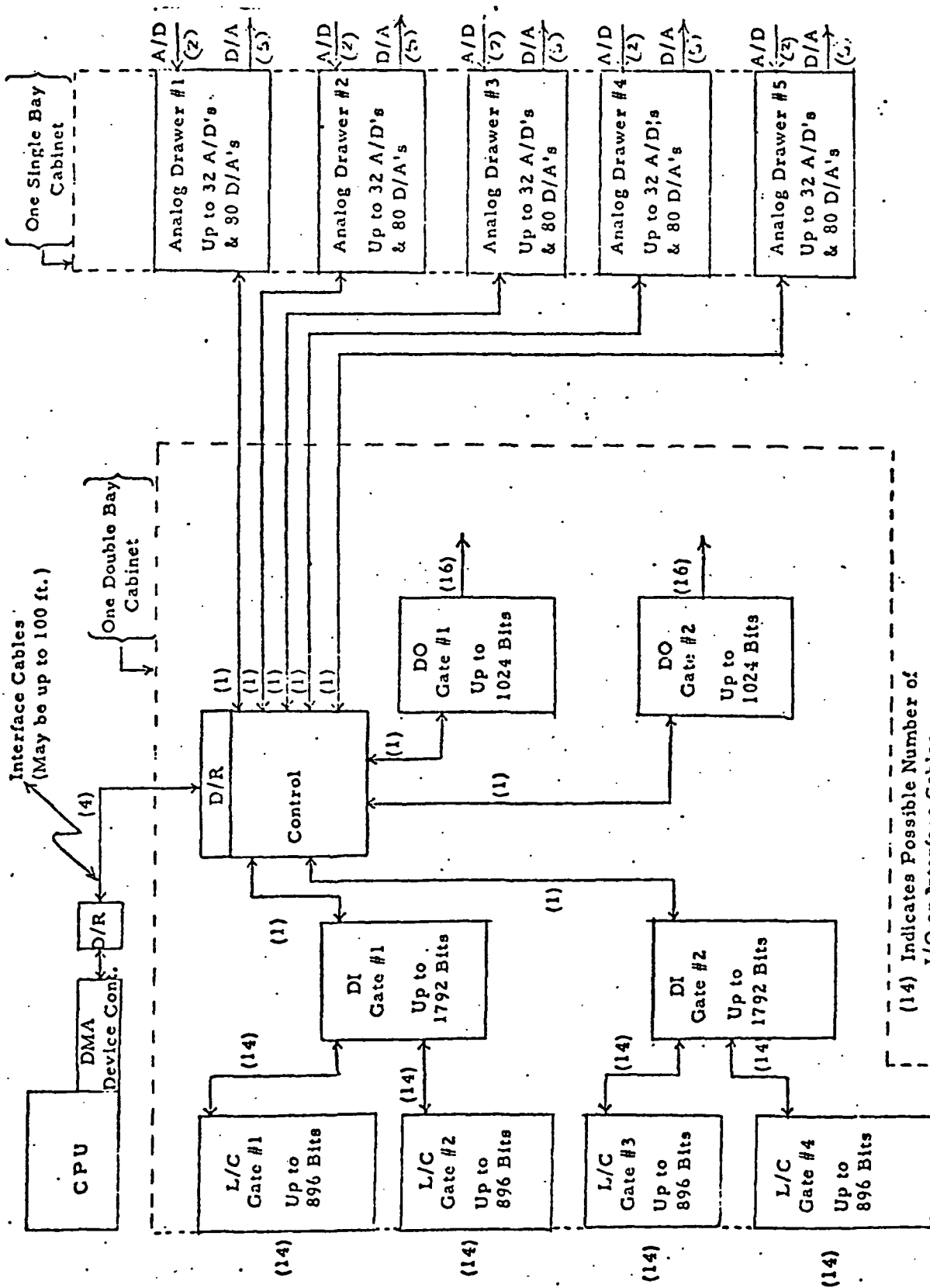
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Figure 3.2.6-1 SPD "T" LINKAGE

Gate Dimensions are nominally 19" x 34" x 4"



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b. DO: Modules of 8 16-bit words expandable to a total of 128 words.

(May be TTL or Lamp Driver DO's chosen in blocks of 8 words.)

c. A/D: Modules of 16 channels expandable to a system total of 192 channels. ( $\pm 10V$  range, 10 bits + sign)

The A/D subsystem utilizes one ADC and 4 8-channels multiplexers for each 32 channels and has low pass filters with a 50 Hz cutoff on each channel.

d. D/A: Modules of 16 channels expandable to a system total of 400 channels. ( $\pm 10V$  range, 10 bits + Sign.)

The analog subsystem is made up of drawers and P/C cards, each drawer having the capability of 32 A/D's and 80 D/A's. The D/A subsystem utilizes a sample/hold technique, with two DAC's utilized for each 80 channels and either 7 Hz or 320 Hz low pass filters on each channel. Filtering selection is applicable to 16-channel blocks.

The Main DCE Controller is configured for full system expansion.

Other features of the system include:

a. High speed, dual differential line driver/receiver system, allowing the DCE system to be up to 100 feet away from the CPU I/O DMA Device Controller.

b. DO & D/A Update fail indication and override (used to interlock simulator DC power and main simulator status). 426<

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c. Hardware DI & DO Bit Processor for packing and unpacking Boolean Bits of DI & DO.

d. Starting channel address and range feature.

e. Analog, subsystem also provides  $\pm 10$  volt reference voltage for simulator A/D signal generation hardware.

f. High speed digital conversion equipment -  $32\mu$ sec average A/D conversion time.  $64\mu$  sec average D/A conversion time. Digital Input & Output transfers at the rate of  $1\mu$  sec per word transfer (exclusive of Computer Overhead).

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### 3.2.6.2.2 Distributed DCE

The technique of Distributed DCE is again based primarily on a packaging scheme, and only indirectly results in the addition or omission of electronics hardware because of a particular packaging and Distribution Methodology. The Basic Distributed DCE System still consists of the necessary electronics hardware (A/D's, D/A's, DO's, Control and steering logic, etc.). However, based on a particular desired configuration, additional multiplexing and demultiplexing electronics and control logic is required for data steering for each "black box" module of DCE equipment around the simulator complex. There are a number of Design philosophies which can be considered in the design of a Distributed DCE System.

1. A central controller and a number of DCE subpackages where each subpackage has the capability of housing all DCE Device Types (D/A, A/D, DI, DO) in various quantities. See Figure 3.2.6-2.
2. A central controller and a number of DCE subpackages where each subpackage has the capability of housing a variable quantity of only one Device Type. See Figure 3.2.6-3.
3. A direct interface to the computer with a controller for each Device type plus a number of DCE subpackages where each subpackage has the capability of housing a variable quantity of the particular Devices. See Figure 3.2.6-4.
4. Figure 3.2.6-5 partially illustrates that, without regard to

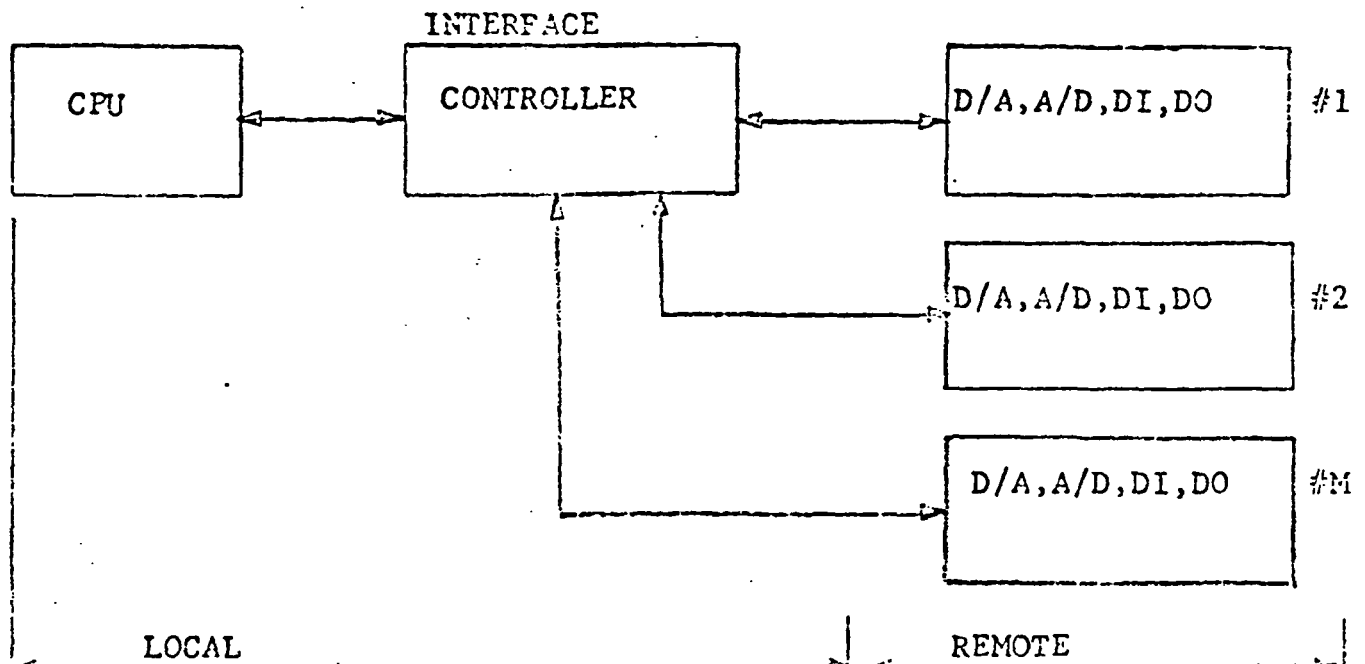
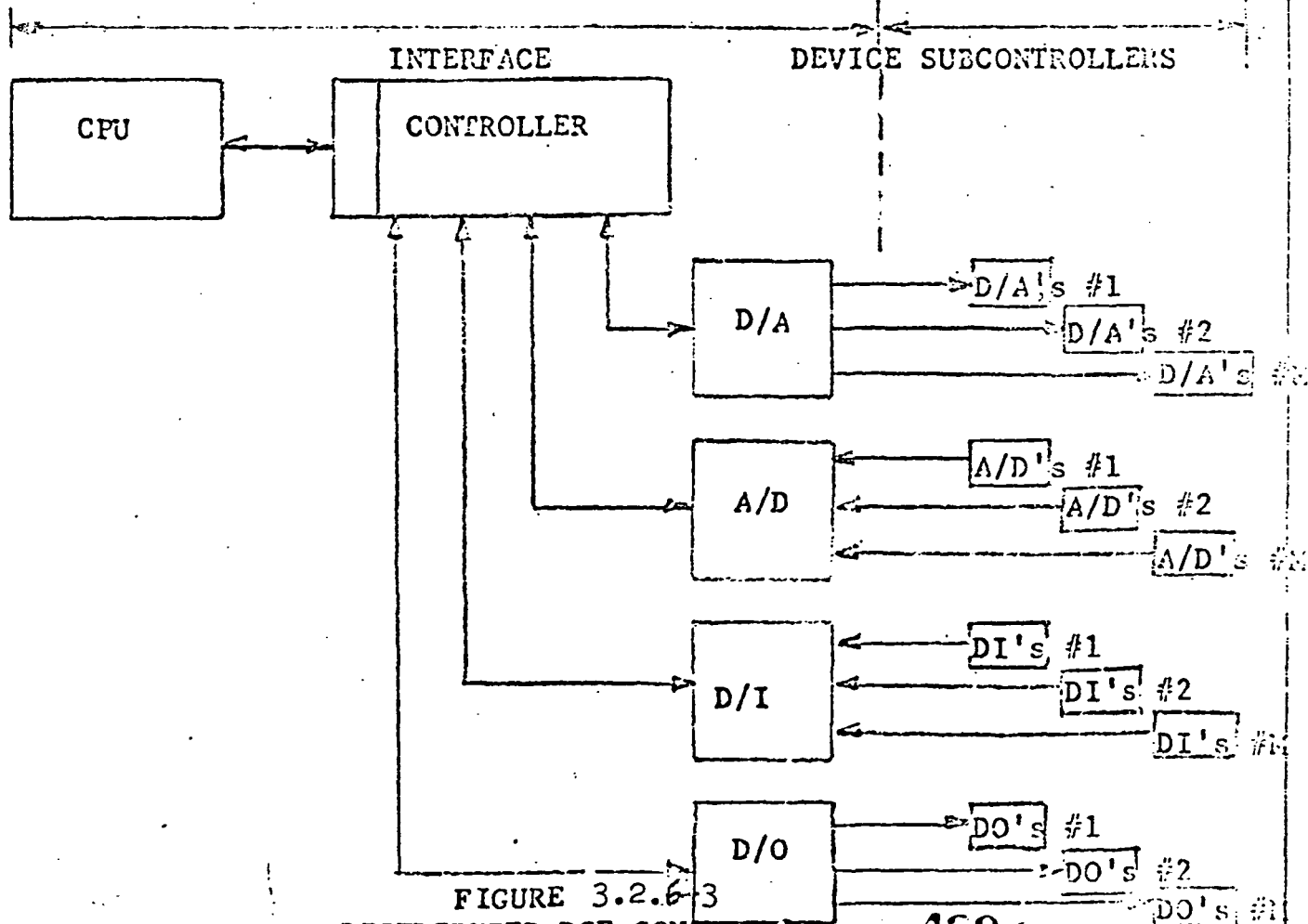


FIGURE 3.2.6-2 DISTRIBUTED DCE CONCEPT A.

FIGURE 3.2.6-3  
DISTRIBUTED DCE CONCEPT B

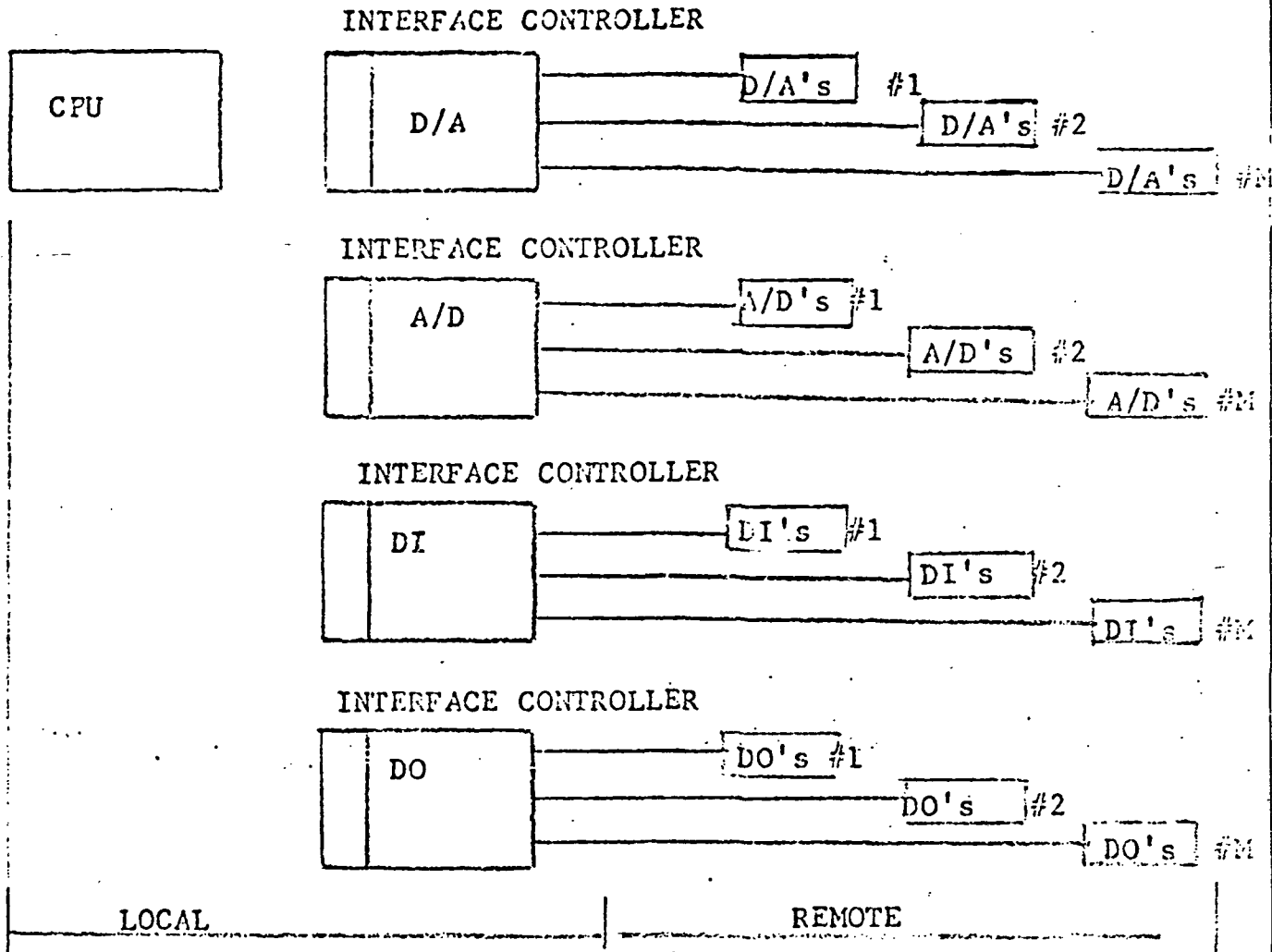


FIGURE 3.2.6-4 DISTRIBUTED DCE CONCEPT C

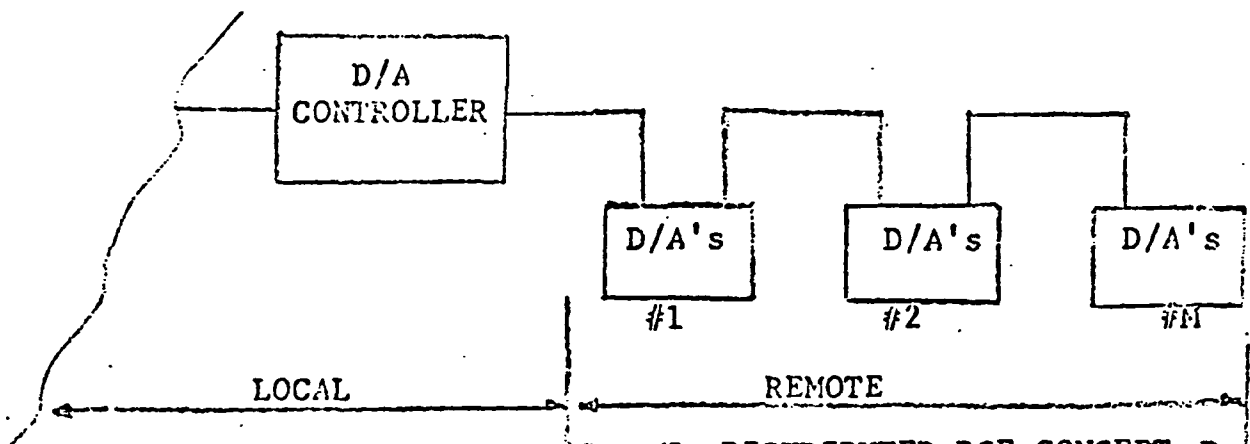


FIGURE 3.2.6-5 DISTRIBUTED DCE CONCEPT D

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interface/control configuration, how the Remote Functional Devices can be daisy chain connected with respect to the Distribution/Collection of Digital Data.

Additional characteristics of a Distributed DCE System are as follows:

1. Update rates and effective data throughput are constrained by the specific interface and control techniques and by the total data path length around the simulator complex.
2. The number of combinations of configurations is practically unlimited.
3. By attention to proper hardware and software design considerations, it is possible to design a system which is directly DCE channel addressable through the use of control words in the I/O Programs (starting channel address and range).
4. In large systems, it can significantly reduce the complexity and bulk of long, signal distribution cables. This can be an important weight and cost factor especially with regard to a large, complex, simulator cockpit/trainee station atop a motion system.
5. By placing the analog conversion devices close to their sources and loads, the overall noise susceptibility of the analog systems can be reduced. Therefore, high resolution and accuracy conversion devices can then be utilized to their fullest potential in the system design sense.

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6. Eliminates need for special interface cabinets.

7. Overall simulator costs (recurring plus non-recurring) may be minimized for one or two unique products.

8. Additional digital transmission electronics, connectors, and more exotic cable types are required.

9. Imposes space and weight penalties in the trainee area.

10. Based on system design and modularity considerations may require a more complex device subaddressing scheme.

11. Where DCE self test or calibration features must be made an integral part of the DCE system, the self test design may become unwieldy and more expensive than in a centralized DCE system.

12. It becomes more difficult at initial design to adequately address the problem of spare channel provisioning for potential growth of the simulator.

13. Design effort and risk increase due to the necessity of evaluating and making provisions for data and control propagation delays through the overall system.

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### 3.2.6.3 Specialized DCE Hardware, Data Handling Techniques

Because of the unique system design goals related to digital simulators, certain techniques have evolved which increase the flexibility of system design and economically provide more powerful means of accomplishing tasks than would otherwise be possible. As can be easily understood, while the digital computer has great versatility in implementing a simulation system, there are certain mundane but necessary tasks which can be carried out more efficiently outside the computer rather than within. The more salient of these items are:

1. Hardware bit processing to pack and unpack digital words in order to collect or distribute boolean bits.
2. Providing; external to the computer, word storage registers containing analog output data for ultimate conversion to analog signals.
3. Provide the capability for Block transfers of data into or out of the CPU to any selected DCE device with input or output commencing at any program selected DCE channel.
4. Provide hardware which will accept a digital word representing an angle and provide the sine of that angle as a digital output.

#### 3.2.6.3.1 Bit Processing

Under software control, via the control lines from the CPU to the DCE system, the particular device type is selected for a block transfer in the normal way except the additional device types are added as noted -



## DBI (Digital Bit Input)

## DBO (Digital Bit Output)

For input transfers, the DCE control logic thus enables the DCE controller to take one DCE DI word of n bits and input it to the computer on a one bit per CPU Byte or one bit per CPU word basis.

For output transfer, the DCE control logic thus enables the DCE controller to accept n Bytes or n words from the CPU and form them into one n bit DCE word for output transfer to the simulator interface.

Particular design details must, of course, be based on the actual computer and its hardware design features.

Characteristics and attributes of this device are as follows:

1. The basic transfer rate is  $1\mu$  sec for each 16-bit digital input or output word (DWI or DWO) and  $8\mu$  sec for each block of 16 digital bit inputs or digital bit outputs (DBI or DBO).
2. DBI's and DBO's must be transferred in blocks of 16 Linkage Word bits.
3. Packing and unpacking is completely under software control.
4. Based on specific design detail and computer instruction implementation, the DCE can accept computer bytes or whole words set to the Boolean value, or only the most or least significant bit of the computer byte or word. The converse is also true for input formats.

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The hardware bit processor relieves the CPU hardware and software of the necessity of packing and unpacking boolean bits, and therefore reduces total CPU time otherwise required.

It provides increased overall system flexibility.

The amount of I/O core required is increased, and the overall DCE data throughput rate is reduced. However, this is not considered significant in relation to the total data transfer accomplished each frame.

The minor reduction of effective throughput is a valid tradeoff against the saving in program time otherwise required to unpack DI words or pack DO words within the CPU.

This technique is utilized fully in the Singer-SPD "T" Linkage as well as the SPD Linkage system being used on the 2F101 (T-2C) simulator. Present existing designs provide for a transformation of each 16-bit linkage DI word into 8, 16-bit computer (PDP-11 series) words. Each computer word is composed of 2 8-bit bytes.

#### 3.2.6.3.2 Analog Output Channel Data Storage

Until recently, with the advent of low cost D/A converter modules, the cost of D/A converters was such that a sample and hold technique was the only cost effective way to design and build analog output DCE systems having the large numbers of channels required by a large simulator (100 to 400 channels).

It is now economically sound to configure an analog output

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system having modular D/A converters and digital word holding registers for each channel. By designing packaging to permit the necessary flexibility, the resolution of the digital data can be economically maintained at 16 bits for all channels. However, less expensive 12, 10, 8, or 6 bit converter modules can be utilized in discretely selected channels as required, to provide a more cost effective total system.

Some of the characteristics of these devices are:

1. Currently designed to accept 8, 10, or 12 bit resolution converters interchangeably.
2. Currently designed with a 16-bit holding register for each channel.
3. Basic digital data transfer time increased to 1  $\mu$  sec per channel exclusive of actual converter settling times.

This results in an extremely cost effective system by comparison to other techniques.

Assuming a DCE Controller with the capability of analog output starting channel address and range, this technique overcomes a strong disadvantage of a sample and hold technique in that continuous update is not required to prevent drift. With starting channel address and range, and with individual holding registers for each analog output channel, increased software efficiencies can, at least potentially, be realized.

With the addition of the individual holding registers it is possible to halt the CPU or single step without the consequent analog

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output signal ambiguities that result in a DCE system using the sample and hold technique. It is also technically feasible to increase the basic throughput rate to the analog output subsystem.

However, with respect to utilization of high resolution (greater than 12 bit) and high accuracy converters in this scheme it is possible to establish a single set of  $\pm 10V$  references for the total system since each converter module presently available has its own internal reference and these cannot be slaved to a common system reference as would be expected in a total system design utilizing a large number of high resolution and accuracy converters. It is presently considered feasible to obtain families of converters having integral storage registers and it is reasonable to expect that new development will yield higher resolution units off-the-shelf in which a single 10 volt system reference can be utilized to improve overall system performance while reducing both long and short term drift.

Problems associated with a requirement to have a common 10 volt system reference are not considered to be necessarily relevant to most simulator applications since accuracies normally required are not stringent as those encountered in such high precision systems.

Singer-SPD's S3A simulator currently utilizes an analog output subsystem configured as described. It is basically a pluggable system in that the basic resolution and accuracy of any particular channel can be chosen merely by selecting the appropriate converter module. All

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interconnected package interfaces are standardized within the system.

### 3.2.6.3.3 Starting Channel Address and Ranging

This technique permits Block Transfers into or out of the CPU to any appropriate DCE Device type with input or output commencing at any program selected DCE channel. The transfer is then carried on via the CPU DMA controller until its word count register is decremented to zero or the program issues a "transfer terminate command".

Characteristics of this technique are as follows:

1. In the specific DCE systems currently designed, the technique is implemented by utilizing a 16 Bit control word as the first word of each Block Transfer from core to establish the starting channel address.
2. Additional I/O time of approximately  $1\mu$  sec for each block of data transferred is required in order to transfer the control word required.
3. Range is established via I/O program control of the word count loaded in the DMA device controller of the CPU.
4. The Real Time I/O Program can override the flag from the Device Controller and terminate the Block Transfer at any time.

This technique provides overall system flexibility in that update rates for the various DCE hardware channels can be made a function of software control only. (If Block Transfers to a particular DCE Device type must always start at channel 0, then devices in the

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simulator which require the highest update rate must always be hard wired as the lowest numbered channels since only range is a controllable parameter.)

Software change flexibility is provided in terms of multi-vehicle configuration simulation growth potential of the DCE system itself, and automatic DCE testing.

The I/O Data Blocks must have an additional control word. (The starting channel number must be in the I/O Data pool.)

This technique is currently implemented in the Basic Designs of Singer-SPD's "T-Linkage" and the Linkage used for the 2F101 (T-2C) simulator.

#### 3.2.6.3.4 Hardware Sine Conversion

The hardware device consists of the necessary digital logic to accept a digital word representing an angle in degrees as an input from the computer and provide the sine of that angle as a digital word at its output back to the computer.

The hardware converter is thus functionally utilized in place of a software subroutine.

In simulation applications, the device is applicable to computing the digital data words required for D/A/R (Digital to Analog to Resolver) and D/A/S (Digital to Analog to Synchro) conversion devices.

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Some of the device characteristics are as follows:

1. High Accuracy (14 Bit input and output) for simulation purposes.

2. Minimizes computer time in direct proportion to the number of Resolver/Synchro Devices in the simulator.

3. Can also be used for other sine subroutine computations not directly related to the DCE equipment.

Implementation of the technique can substantially reduce computer loading in simulators utilizing large numbers of D/A/R's and/or D/A/S's.

Singer-SPD's simulators currently utilizing the SPD "T-Linkage" also use a hardware sine converter operating as a CPU peripheral device interfaced to a program controlled device channel on the CPU (PDP-11 series).

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#### 3.2.6.4 Baseline DCE Configuration

The principle tradeoffs worthy of serious consideration in selecting the Baseline SMS DCE configuration have been:

1. Non-recurring and recurring cost and complexity
2. Reliability/Maintainability requirements
3. SMS requirements in terms of layout, growth, versatility, etc.
4. Program risk, both in the area of technical development and maintaining an optimum program plan as established.
5. Operational speed and I/O time
6. Long term system versatility
7. Minimization of long term operating cost and complexity with respect to changes which may be required in the SMS hardware and software above an initial delivered configuration.

The Baseline DCE system should have the potential of satisfying both short and long term growth potential, with the growth potential being additive at minimum cost and calendar schedule impact. However, weight and space requirements preclude the mounting a large DCE equipment on the motion system platform. Therefore a modified DCE system configuration will be provided for the SMS.

Future developments in MSI and LSI circuitry in the next year or two may allow development of a more completely distributed DCE system capable of closed loop test, economically and with lower risk than at present.



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The MBCS DCE requirements are summarized in Table 3.2.6-1.

The baseline system will take the form of the "T" linkage DCE described in Section 3.2.6.2.1, but will be distributed to the MBCS, to the FBCS and to the remotely located visual system cabinet areas if required. Figure 3.2.6-6 is a block diagram of the presently recommended SMS DCE configuration.

In the baseline configuration, computer interfacing of the SMS DCE equipment will be accomplished utilizing two separate Mini Computer I/O systems; one for the Motion Base Crew Station and one for the Fixed Base Crew Station. This scheme effectively splits the data and time loading as opposed to using only one DMA channel for the entire DCE system. It permits a high average through-put rate and is considered adequate in the light of the cost and risk of developing more exotic techniques. It also effectively divides the DCE into two deliverable entities, one for the MBCS and one for the FBCS.

Hardware bit-processing will be provided for Digital Outputs and the analog output system will include the buffered storage technique to provide increased performance flexibility and at least potentially, reduce software loading. Starting channel address and ranging will also be considered a mandatory requirement of the DCE system to provide the inherent system flexibility it offers in comparison to cost or complexity.

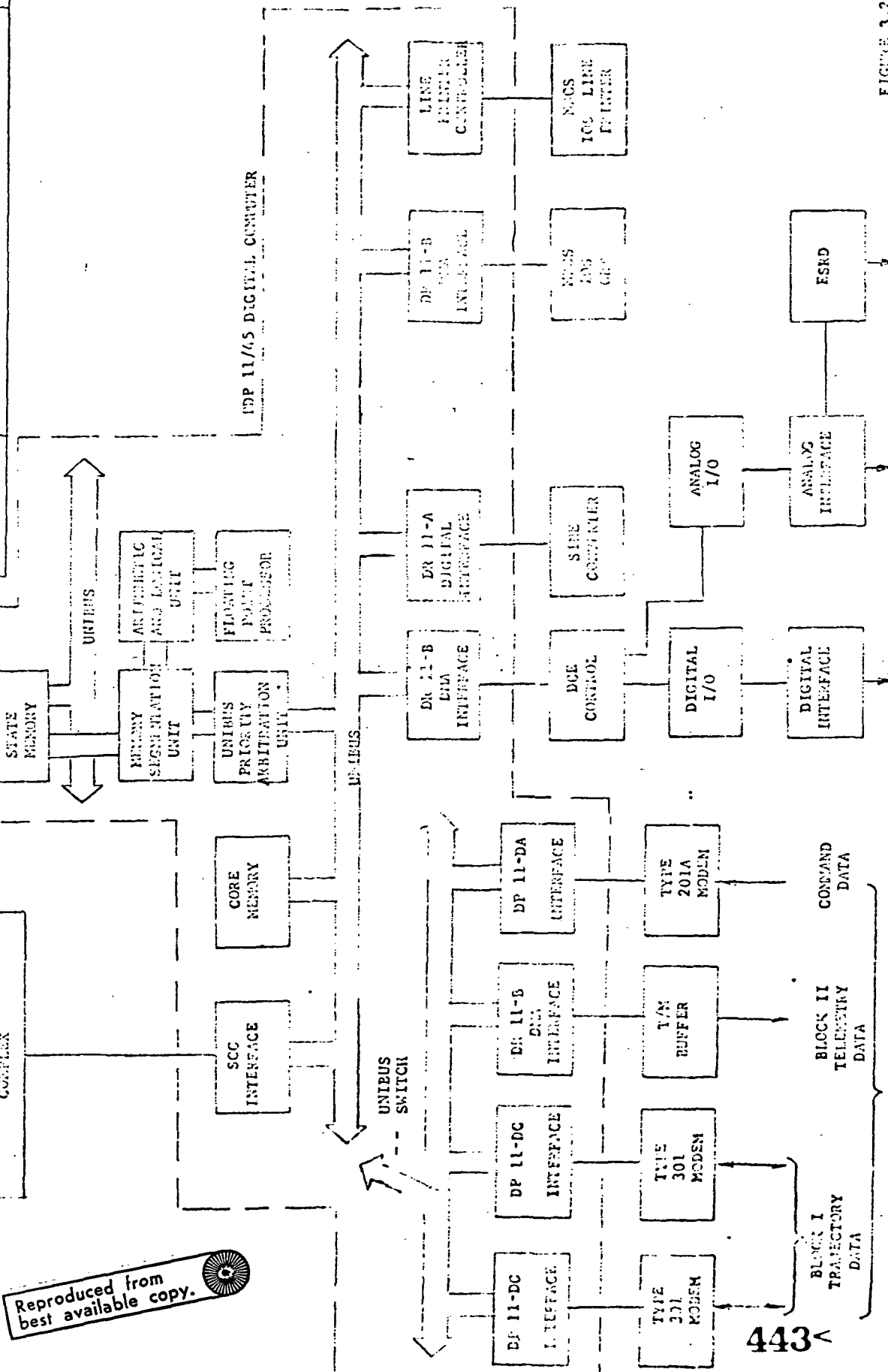


FIGURE 3.2.6-6  
BLOCK DIAGRAM MODES FOR SYSTEM

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|                                | <u>Analog<br/>Input</u> | <u>Analog<br/>Output</u> | <u>Discrete<br/>Input</u> | <u>Discrete<br/>Output</u> | <u>ESRD</u> |
|--------------------------------|-------------------------|--------------------------|---------------------------|----------------------------|-------------|
| Motion Base Crew Station       |                         |                          |                           |                            |             |
| Crew Station                   | 34                      | 156                      | 1765                      | 1436                       | 30          |
| Instructor/Operator<br>Station | 1                       | 98                       | 119                       | 303                        | 30          |
| Motion                         | 7                       | 8                        | 1                         | 2                          |             |
| Visual (MB & FB)               |                         |                          | 328                       | 1216                       |             |
| Aural Cue                      |                         | 70                       |                           |                            |             |
| Voice Communications           |                         | 6                        |                           | 67                         |             |
| Sub Total                      | 42                      | 338                      | 2213                      | 3024                       | 60          |
| Spare at 25%                   | 11                      | 85                       | 554                       | 756                        | 15          |
| Total Required                 | 53                      | 423                      | 2767                      | 3780                       | 75          |
| Total Provided                 | 64                      | 480                      | 3584                      | 4096                       | 80          |
| Wired for Expansion to         | 96                      | 480                      | 3584                      | 4096                       | 108         |

Table 3.2.6-1  
MBCS DCE REQUIREMENTS

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Digital Input data is required in a packed form to be compatible with the software requirements of the Event Time Monitor program. Hence it will also require unpacking by a software program. However, Digital Outputs can be left unpacked and processed by the DCE hardware.

In addition, present estimates indicate that the MBCS requirement for Electronic Synchro Resolver Drivers is approximately 75.. At twenty iterations per second, the implication is a calculation of 1500 sine functions per second. The average execution time of a sine function subroutine is approximately 100 microseconds. Hence, approximately 150,000 microseconds per second of time could be required for this function in the mini computer which drives the DCE. Therefor, a hardware sine function generator will be provided to supplement the DCE mini computer.

The DCE mini computer will also be utilized for analog I/O data scaling, fixed floating conversions and for control and formatting of the Trajectory, Telemetry, and Command Data transmissions to and from M.C.C. It will also provide formatting and control for the MBCS IOS CRT system.

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Analog Inputs to the DCE minicomputers consist of fixed point data (10 bits plus sign). One data word is stored in a 16 bit PDP11/45 computer word scaled as indicated in section 3.2.6.4.1.2 of the SMS Baseline Report.

Each analog input word will be converted to a 32 bit floating point word (two 16 bit half words) for transmission to the S.C.C. The single precision Floating point format consists of a sign bit, eight bits for the exponent and 23 bits for the fraction. This is consistent with the IBM/370 floating point data format.

Analog data outputs from the DCE minicomputer are of the same format as analog inputs. Thirty-two bits floating point data from the SCC will be converted to 16 bit fixed point halfword data prior to output. Hence, each analog input and output will require a total of three PDP11 16-bit halfwords of buffer memory.

In addition, synchro devices will require outputs of the Sine  $\theta$  and Sine  $(\theta+90)$ .

Therefore Floating Point Angular data for these devices will be converted to fixed point 16 bit data, outputted to the Sine converter hardware, recovered in trigonometric form, and re-outputted to the Analog output hardware.

Digital Input Data may be Digital Word Input (DWI) or Digital Bit Input (DBI).

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Digital Word Inputs are transferred to the PDP 11 in a 16 bit packed form. As an option Digital Bit Input data may be converted by the DCE from 16 bit packed form to a one discrete bit per byte format, where all bits per byte have the same logic state ("1" or "0") as the single DCE bit. However, it is presently planned to input all discrettes in packed form and unpack discrettes by use of a software subroutine.

These DWI inputs will be formatted by the DCE minicomputer to a format compatible with the requirements of the SCC applications software programs. (1 bit per halfword)

Conversely, digital output data; Digital Word Outputs (DWO) or Digital Bit Outputs (DBO) will be received from the SCC and formatted prior to transmittal to the DCE. DBO will be transmitted to the DCE in a one bit per byte format.

The format for Block I trajectory data is assumed to be as specified in section 6.2.5.8.1.1.2 of the SMS Requirements Report.

This data will be received and transmitted in serial form at a rate of 40.8 kilobits per second per line from the GSSC to the SMS MBCS DCE minicomputer.

The Minicomputer will provide buffering and fixed to floating, floating to fixed conversions of this data as required.

Telemetry data from all simulated subsystems will be received from the SCC computer in floating point or discrete data format.

The data will be formatted, packed, and converted to the required output

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format by the minicomputer, and outputted to a buffer for parallel to serial conversion.

Digital Command System Data will be received by the SMS MBCS DCE Minicomputer, as 2.36 kilobit per second serial digital data, converted to 16 bit parallel data, formatted, buffered, and retransmitted to the S.C.C.

Estimates for the DCE minicomputer memory and time requirements have been revised based upon new DCE requirements for the visual system, and are summarized in Table 3.2.6-2 for the MBCS.

It is assumed that assembly language will be used for the programming of these minicomputers.

The Executive/Monitor, MasterControl/ Timing program and the subroutine library loadings are based on actual code counts of the T2C/2F101 simulator.

In the MBCS DCE minicomputer, data buffers will be required as follows:

|                         | SCC/Mini  | Mini/I/O  | Total  |
|-------------------------|-----------|-----------|--------|
| Analog Input            | 106       | 53        | 159    |
| Analog Output           | 846       | 423       | 1269   |
| Digital Input           | 2767      | 173 + 173 | 3113   |
| Digital Output          | 3780      | 1890      | 5670   |
| Sine Conversions        |           | 75        | 75     |
| Sub Total               |           |           | 10,286 |
| Block I Trajectory Data | 316 + 324 | 316 + 324 | 1280   |
| Block II Telemetry      | 3000      | 2123      | 5123   |
| Command Data            | 8         | 8         | 16     |
| IOS CRT Data            | 1140      | 22800     | 23,940 |

TABLE 3.2.6-2  
MBCS DCE & IOS CRT CONTROL  
MINICOMPUTER LOADING ESTIMATE

SINGER-GENERAL PRECISION, INC.

LINK DIVISION

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| PROGRAM ELEMENT           | INSTRUCTIONS | DATA   | TOTAL<br>MEMORY | RATE | LOOPING | TOTAL<br>LOOPS | MICRO<br>SECONDS<br>PER<br>LOOP | MICROSECONDS<br>PER<br>SECOND |
|---------------------------|--------------|--------|-----------------|------|---------|----------------|---------------------------------|-------------------------------|
| EXECUTIVE/MONITOR         | 6000         | 1000   | 7000            | 20   | 1       | 20             | 1000                            | 20,000                        |
| MASTER CONTROL AND TIMING | 1000         | 200    | 1200            | 20   | 1       | 20             | 100                             | 2000                          |
| ANALOG INPUT PROCESSING   | S.R.         | 159    | 159             | 20   | 53      | 1060           | 9.6                             | 10,176                        |
| ANALOG OUTPUT PROCESSING  | S.R.         | 1,269  | 1,269           | 20   | 423     | 8460           | 9.8                             | 82,908                        |
| EXP. DRIVE                | S.R.         | 75     | 75              | 20   | 75      | 1500           | 7.4                             | 11,100                        |
| DIGITAL INPUT PROCESSING  | S.R.         | 3,113  | 3,113           | 20   | 173     | 3460           | 6.8                             | 23,528                        |
|                           |              |        |                 | 20   | 5       | 100            | 10                              | 2,000                         |
| DIGITAL OUTPUT PROCESSING | S.R.         | 5,670  | 5,670           | 20   | 1890    | 37,980         | 5.4                             | 204,120                       |
| BLOCK I TRAJECTORY DATA   | 300          | 1,280  | 1,580           | 20   | 69      | 1380           | 10                              | 13,800                        |
| BLOCK II TRAJECTORY       | 2000         | 5,123  | 7,123           | 20   |         |                |                                 |                               |
| COMMAND DATA              | S.R.         | 16     | 16              | 20   | 1       | 20             | 200                             | 4,000                         |
| IOS CRT DRIVE             | 10,000       | 23,940 | 34,940          | 1    | 6       | 6              | 10,000                          | 60,000                        |
| SYSTEM TIME LIBRARY       | 2,000        | --     | 2,000           |      |         |                |                                 |                               |
| SUBTOTAL                  |              |        | 64,245          |      |         |                |                                 | 732,632                       |
| SPARE AT 31% of Used      |              |        | 21,415          |      |         |                |                                 | 244,211                       |
| TOTAL                     |              |        | 85,650          |      |         |                |                                 | 976,843                       |



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As indicated, Analog I/O data will require a total of three halfwords of storage per data item. Two halfwords are required for the floating point format, and one halfword for the fixed point format.

Analog Inputs require conversion from fixed point to floating point format, while analog outputs require conversion from floating point to fixed point conversion.

In addition, synchro devices require the Sine  $\theta$  and Sine  $(\theta+90)$  outputs.

Conversion of data from fixed to floating point format or floating point to fixed point format will be achieved by the floating point hardware option on the PDP11/45.

Each conversion requires approximately 9 Microseconds including set up time. However, this activity occurs partially in parallel with other CPU arithmetic unit operations.

Digital Input data from the DCE will be received as packed words by the minicomputer. Each of the words will be compared with its past value, and if the word has changed, the word will be unpacked and each bit will be stored in a buffer prior to transmission to SCC.

The computer loading estimate for the DI unpacking process is based upon the assumption that each packed DI word will be

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sampled at 20 ips and that an average of 5 words will change per 50 millisecond iteration.

#### Block I Trajectory Data

It is assumed that Block I Trajectory Data received from GSSC will require fixed to floating point conversion and that data transmitted to GSSC will require floating to fixed point conversion. This data consists of time data, state vector data for the Shuttle and targets, command data and communications system data, plus various message validity and identification data words. (Reference SMS Requirements Report, page 125A.)

It is presently estimated that 69 data items will require conversion per iteration at an average conversion time of 10 micro seconds.

#### Block II Telemetry Data

There are presently a total of 2123 parameters identified in the master measurements list for the Shuttle. Of these, 1000 are analog and 1100 are discrete. Each measurement parameter will be transmitted from the SCC to the DCE minicomputer as block tables in floating point format or as discrete type data as one bit per halfword.

Some of the operations which the PDP11/45 must perform are:

- o Scaling
- o Signal Conditioning

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- o Float to Fixed conversions
- o Buffering
- o Multiplexing
- o Add frame identifiers
- o Add subframe identifiers
- o Add in time information
- o Pack booleans into words
- o Execute Multiplexer failures as directed by an SCC program.
- o Add in upper and lower limits and offsets

Two telemetry formats are required for output. One format will be the true value available to the T/M console operator CRT display. The display is in fixed point format - the binary equivalent of a 0-5 volt range. The other format includes malfunctions inserted in the data prior to transmission to MCC.

IOS CRT Display System data transmitted from the SCC to the DCE minicomputers will consist of tables of display data in SCC floating point format and pointers to data within each table which has changed since the last refresh.

Each CRT can display up to 2400 alphanumeric characters (30 lines of 80 characters). The CRT refresh memory will hold up to 3800 characters. ASCII format is utilized.

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It is presently estimated that approximately 100 conversions will be required each update per CRT, with an estimated 12 characters of data to be processed per conversion.

Estimates of Input/Output data transfers from the MBCS DCE minicomputer have been made based upon available data and are shown in Table 3.2.6-3.

Each Unibus access requires approximately 500 nano seconds. Therefore Unibus access time will be approximately 0.166 seconds per second for the MBCS DCE Minicomputers respectively.

MBOS DCE MINICOMPUTER I/O

|               |   |                    |
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| SCC/MINICOMPUTER INTERFACE |       |              |                       |                           |                       |                  |                  |           |                        |              |                      | MINI-SMS INTERFACE |  |  |  |
|----------------------------|-------|--------------|-----------------------|---------------------------|-----------------------|------------------|------------------|-----------|------------------------|--------------|----------------------|--------------------|--|--|--|
| FUNCTION                   | SPARE | DATA WORDS   | SCC FORMAT            | I/O CHANNEL FORMAT        | I/O CHANNEL HALFWORDS | I/O CHANNEL RATE | HALFWORDS SECOND | HALFWORDS | FORMAT                 | RATE         | HALFWORDS PER SECOND |                    |  |  |  |
| ANALOG INPUT               | 25%   | 53           | 32 BIT FLOATING POINT | 2 HALFWORDS               | 106                   | 20               | 2,120            | 53        | FIXED POINT            | 20           | 1060                 |                    |  |  |  |
| ANALOG OUTPUT              | 25%   | 423          | 32 BIT FLOATING POINT | 2 HALFWORDS               | 846                   | 20               | 16,920           | 423       | FIXED POINT            | 20           | 8460                 |                    |  |  |  |
| DIGITAL INPUT              | 25%   | 2767         | 1 BIT                 | BIT/HALFWORD              | 2767                  | 20               | 55,340           | 173       | BIT/BYTE               | 20           | 3460                 |                    |  |  |  |
| DIGITAL OUTPUT             | 25%   | 3780         | 1 BIT                 | BIT/HALFWORD              | 3780                  | 20               | 75,600           | 1890      | BIT/BYTE               | 20           | 37800                |                    |  |  |  |
| BLOCK I TRAJECTORY DATA    | --    | 130<br>30    | 32 BIT FLOATING POINT | 1 HALFWORD                | 260<br>60             | 10<br>20         | 2,600<br>1,200   | N/A       | MODEM SERIAL           | *(1)         | 2600<br>1200         |                    |  |  |  |
| BLOCK II TELEMETRY         | --    | 1061<br>1062 | 32 BIT FLOATING POINT | 1 HALFWORD<br>2 HALFWORDS | 1061<br>2124          | 20<br>20         | 21,220<br>42,480 | N/A       | DNA OUTPUT<br>HALFWORD | 4000<br>*(2) | 8000                 |                    |  |  |  |
| COMMAND DATA               | --    | 8            | MIXED                 | 1 HALFWORD                | 8                     | 20               | 160              |           | SERIAL                 | *(3)         | 160                  |                    |  |  |  |
| LOS CRT DISPLAY SYSTEM     | --    | 22800        | MIXED                 | 1 HALFWORD                | 1140                  | 20               | 22,800           |           | HALFWORD               | *(4)         | 22,800               |                    |  |  |  |
| MECS SINE CONVERSIONS      | 25%   |              |                       |                           |                       |                  |                  | 75(6)     | FIXED POINT            | 20           | 6000                 |                    |  |  |  |
| TOTAL                      |       |              |                       |                           |                       |                  | 240,440          |           |                        |              | 91,540               |                    |  |  |  |

- \*(1) REFERENCE SMS REQUIREMENTS REPORT, VOL. I, PAGE 125A, REV. B. 6/22/73  
MAXIMUM OF 3 TARGETS AT ONE TIME. 50K BITS/SEC. SERIAL DATA
- \*(2) REFERENCE SMS REQUIREMENTS REPORT, VOL. I, PAGE 126, REV. B. 6/22/73  
12K BITS/SECOND DATA RATE
- \*(3) REFERENCE SMS REQUIREMENTS REPORT, VOL. I, PAGE 124, REV. B. 6/22/73  
2360 BITS/SECOND DATA RATE
- \*(4) SIX CRT DISPLAYS UPDATED ONCE PER SECOND. MAXIMUM OF 3000 ASCII CHARACTERS PER DISPLAY MEMORY (2400 DISPLAYABLE CHARACTERS PER CRT). ALSO ASSUME 220 CONVERSIONS PER SECOND, 12 CHARACTERS PER CONVERSION, IN SCC. MINI WILL PROVIDE BUFFERING.

TABLE 3.2.6-3

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#### 3.2.6.4.1 Baseline DCE System Elements

The baseline DCE System for the MBCS will consist of a double-bay cabinet for DCE/Mini Computer drivers and receivers, a single bay cabinet for analog I/O power and control, a double bay cabinet for analog I/O and two double bay cabinets for digital I/O. All power supplies are integral to the system and equipped with over-voltage sensing and protection devices. Interlocks are provided for the monitoring of linkage power and system processing.

A status and monitor panel consisting of power and processing monitors, interlock override controls, and main power circuit breakers is provided in each of the linkage cabinets. The status annunciators indicate the state of each power supply, and the processing status for each of the analog units. The override enables overriding the automatic interlock for each of the monitored functions. The override will close the interlock path but will not affect the failed status of the affected unit.

This equipment has been developed as an entirely solid-state electronic system by Singer-SPD and is now offered as the most effective system for meeting the rigorous real-time data transfer demands of training devices. The linkage system is designed with modularity as a basic requirement. It incorporates a hybrid packaging technique consisting of planar packaging of digital system components, and conventional printed circuitry for the analog functions of the linkage system. All active components utilized in the system are in the

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form of integrated circuits to provide high reliability and ease of maintenance.

The analog printed-circuit cards are mounted on swing-out, hinged gates measuring approximately 19 x 35 inches and contain integral I/O connectors which are individually keyed. The intercard wiring, which uses card connector pins, is conveniently accessible. Cable connectors on the rear of the gates are arranged so that cables go directly from the gates to other equipments, thus reducing the intracabinet wiring and eliminating the need for additional connectors at the bottom of the cabinet. The digital system is packaged utilizing a planar packaging technique. All logic elements are plugged directly into a machine wire-wrapped backplane. The backplanes are mounted on hinged gates with easy access to the plug-in modules and the associated backplate wiring.

#### 3.2.6.4.1.1 Control

The control module is composed of two sections: a "common" control for the I/O systems and a "front end" control for interfacing with the digital computer. The "common" control performs the function of transferring computer words, at system iteration rates, to and from the I/O systems and the computer. The "front end" control acts as an interface between the linkage I/O systems and the computer direct memory access I/O port.

The basic digital data transfer rate of the linkage system, exclusive of computer overhead, is one data word exchange every 2

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microseconds. In the case of analog output transfers, the system requires 128 microseconds delay for conversion after each second data word transfer. Analog input transfers require 32 microseconds settling time delay.

3.2.6.4.1.2 Analog Input System

The analog input system consists of a multichannel analog multiplexer, a sample-and-hold amplifier, and a single-channel A/D converter in each of two analog gates. The sample-and-hold amplifier enables multiplexer settling and A/D conversion to be performed simultaneously, thereby reducing the overall conversion time per channel to 32 microseconds. The following specifications apply:

|                          |                          |
|--------------------------|--------------------------|
| Resolution               | 11 Bits (10 Bits + Sign) |
| Accuracy                 | 0.05% Full Scale         |
| Input Voltage Range      | $\pm 10$ Volts           |
| Maximum Source Impedance | 5,000 Ohms               |

The linkage system provides a  $\pm 10$ -volt reference for analog input signals. A/D data transfer is accomplished in negative 2's complement with bit weights as defined below:

|       |   |
|-------|---|
| Bit 0 | Sign ("0" - Positive)<br>("1" - Negative) |
| Bit 1 | Sign                                      |
| Bit 2 | Sign                                      |
| Bit 3 | 5 Volts                                   |



Bit 4 2.5 Volts

.  
.  
.

Bit 12 0.00977 Volts

3.2.6.4.1.3 Analog Output System

The analog output system consists of two ladder networks and up to 80 sample-and-hold circuits in each of two analog gates. Each ladder is preceded by a flip-flop buffer register. This register holds the digital word while the conversion is performed by the ladder network. Each ladder network can receive and convert a new quantity every 128 microseconds. Since two networks are in simultaneous operation, an average time per word of 64 microseconds is achieved. The following specifications apply to each channel:

|                         |                                 |
|-------------------------|---------------------------------|
| Output Voltage Range    | +10 Volts                       |
| Output Drive Capability | 5 Milliamperes                  |
| Sample Time             | 128 Microseconds                |
| Hold Time               | 50 Milliseconds                 |
| Output Response Time    | 50 Milliseconds (time constant) |
| Accuracy                | $\pm 0.1\%$ full scale          |
| Output Impedance        | Less than 1 ohm                 |
| Resolution              | 11 Bits (10 bits + sign)        |

D/A data transfer is accomplished in negative 2's

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complement format with the same bit weighting as the analog input system.

#### 3.2.6.4.1.3.1 Analog Converter Resolution

On the basis of previous experience in the design and production of many military and commercial simulators, and Singer-SPD's evaluation of the SMS instrumentation, there is no doubt that the base-line analog input/output conversion systems have the necessary resolution and accuracy required not only to meet, but to surpass the overall systems requirements of the SMS simulator. Where long scale lengths are encountered in the system design, such as an altimeter, the basic simulated instrument will be designed as a multi-speed servo in which the fine control signal is scaled to provide the necessary resolution and accuracy in the overall simulation design. Similarly, a review of all analog input signal generation equipment indicates that there is no instance where the overall A/D conversion resolution is not at least twice the particular control tolerance.

#### 3.2.6.4.1.4 Digital Input System

The digital input system periodically samples discrete switch or control inputs from the simulator at high speed and transmits them to the computer. The system consists of a large number of gates which sample the switches under the control of the real-time input/output system and feed them into a single output cable. The speed of the system is limited only by the computer iteration rate. For the MBCS, the maximum necessary iteration rate will be 20 per second.

The DI system is DTL, TTL-compatible and has integral pullup resistors to VCC.

The system operates with each bit meeting the following specifications:

|                 |                          |
|-----------------|--------------------------|
| Logic "1" Input | +2.4 Volts, Nominal      |
|                 | +5.0 Volts, Maximum      |
|                 | +2.0 Volts, Minimum      |
| Logic "0" Input | Ground, 0 Volts, Nominal |
|                 | +0.8 Volts, Maximum      |
|                 | 0 Volts, Minimum         |

#### 3.2.6.4.1.5 Digital Output System

The digital output system takes digital words from the computer, strobes them into its own flip-flop memory, and uses the individual high-speed solid-state switches to set trainer relays, or to illuminate lamps. Because of its internal storage capacity, it can accept words at high speed and operate relays and lamps at a frequency equal to the computer iteration rate.

Two types of digital output signals are available:

(1) low-level logic output signals suitable for driving DTL or TTL loads, and (2) high-level current drivers for actuation of lamps or relays. The low level logic output incorporates an active pullup voltage for the "off" condition, while the lamp/relay output does not. The output characteristics are as follows:

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|                                       | <u>Lamp/Relay<br/>Driver Output</u> | <u>Logic Output</u> |
|---------------------------------------|-------------------------------------|---------------------|
| Logic "1" output current              | 250 ma                              | 10 ma               |
| voltage                               | 1.5 volts (max)                     | 0.4 volts (max)     |
| Logic "0" output current              | -----                               | 400 $\mu$ a         |
| voltage                               | open                                | 2.4 volts (min)     |
| Reverse voltage (logic "0"<br>output) | 30 volts                            | 7 volts             |
| Maximum switching rate                | 60 Hz, 50% Duty Cycle               | -----               |
| Ground Reference                      | R-Ground                            | D-Ground            |

#### 3.2.6.4.1.6 Synchro Conversion System

The synchro conversion system will provide the drive signals for the various synchro-type instruments within the MBCS. The system will be configured to provide 80 individual synchro signal channels, with provision for expansion up to 108 channels by the addition of only printed-circuit cards. The converters will have the capability of operating as torque transmitters and will exhibit the following characteristics:

Amplitude: 0 to 11.8 volts RMS, 400 hz  
(3-wire synchro output)

Harmonic Distortion: 1.5% (maximum)

Static Accuracy:  $\pm 12$  arc minutes

#### 3.2.6.4.1.7 Conversion Equipment Self-Test

The simulator peripheral electronics will include various subsystems which will permit the complete testing of all digital and analog conversion equipment, including synchro signal generation hard-

ware. These subsystems are described in detail in the following paragraphs. All are full-wraparound, closed-loop signal control devices wired for the complete complement of I/O channels of each type. The operation of each will be initiated under computer control via the linkage test programs, and in the self-test mode all signals to or from the simulator will be totally disconnected automatically.

#### 3.2.6.4.1.7.1 Digital Conversion Self-Test

A block diagram of the digital conversion equipment self-test hardware is shown in Figure 3.2.6-8. This subsystem is wired to test all input and output bits. The software will test all input and output discrete bits by establishing data patterns and verifying expected results to test each device in both logic states. Through the use of other resident software, hardcopy test results will be printed out to identify any failed channels. Operator intervention in the test will be minimum, requiring only entry of test commands via the portable computer I/O console CRT.

#### 3.2.6.4.1.7.2 Analog Conversion Self-Test

A block diagram of the analog conversion equipment self-test hardware is shown in Figure 3.2.6-9. This subsystem will be wired for the full analog conversion system, including spares and growth (160 D/A and 64 A/D channels).

The entire analog system will be tested to the channel level, with each channel operated over its entire range dynamically via the linkage test programs, thus verifying the operability of all

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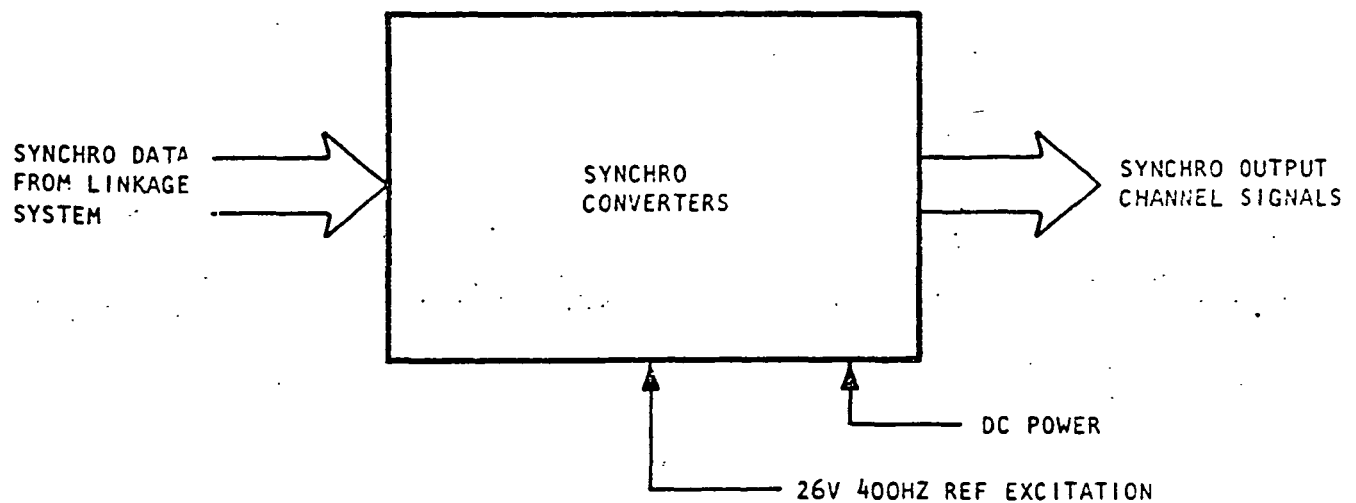


Figure 3.2.6-7

SYNCHRO OUTPUT SIGNAL CONVERSION EQUIPMENT

|                |  |                   |
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analog system components. Analog tests will be initiated via entry commands from the console CRT. The operator will have the option of entering a go-no-go limit value into the test program at the time the testing is begun. All analog test data will be evaluated by the test program on the basis of calibration data loaded as a part of the analog test program. Hardcopy test results will be printed out, identifying any failed channels.

#### 3.2.6.4.1.7.3 Synchro Conversion Self-Test

A block diagram of the synchro conversion equipment self-test hardware is shown in Figure 3.2.6-10. This device will be wired for the full synchro conversion system, including spares and growth (216 channels). The entire synchro conversion system will be tested to the channel level, with each channel operated over its entire range dynamically via the linkage test program, thus verifying the operability of all synchro conversion system components. Synchro signal tests will be initiated via entry commands and the operator will have the option of entering a go-no-go limit value to the test program at the time the testing is begun.

The synchro-to-digital converter utilized in the self-test device will have a resolution of 14 bits to assure its accuracy in evaluating synchro output signals to the simulator. Hardcopy test results will be printed out, identifying any failed channel.

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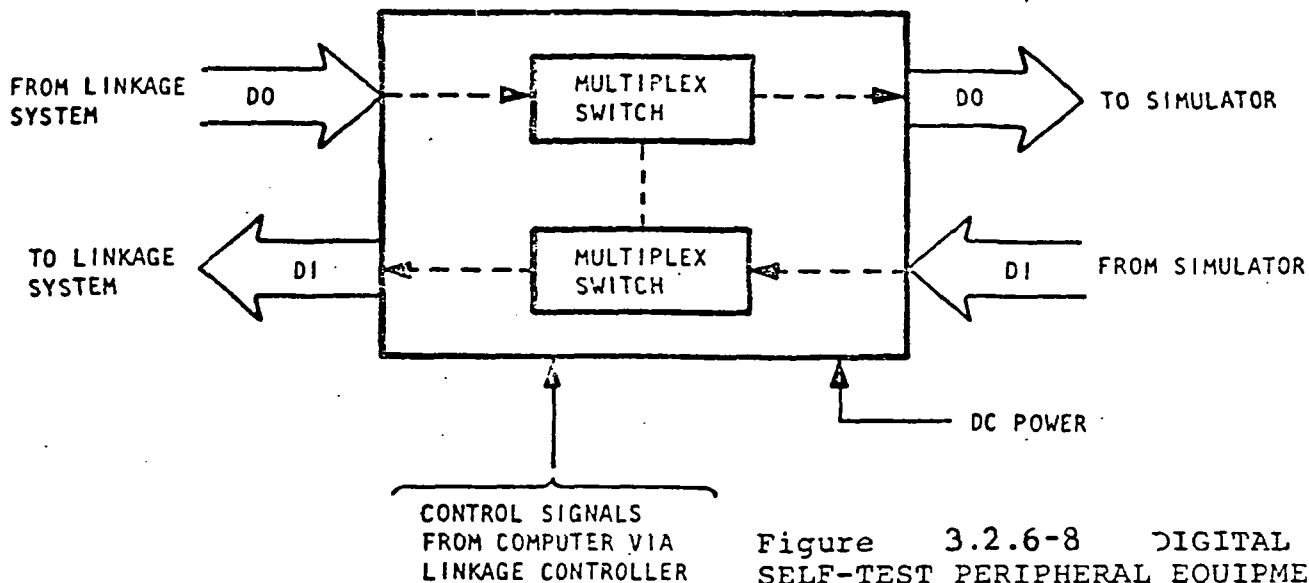
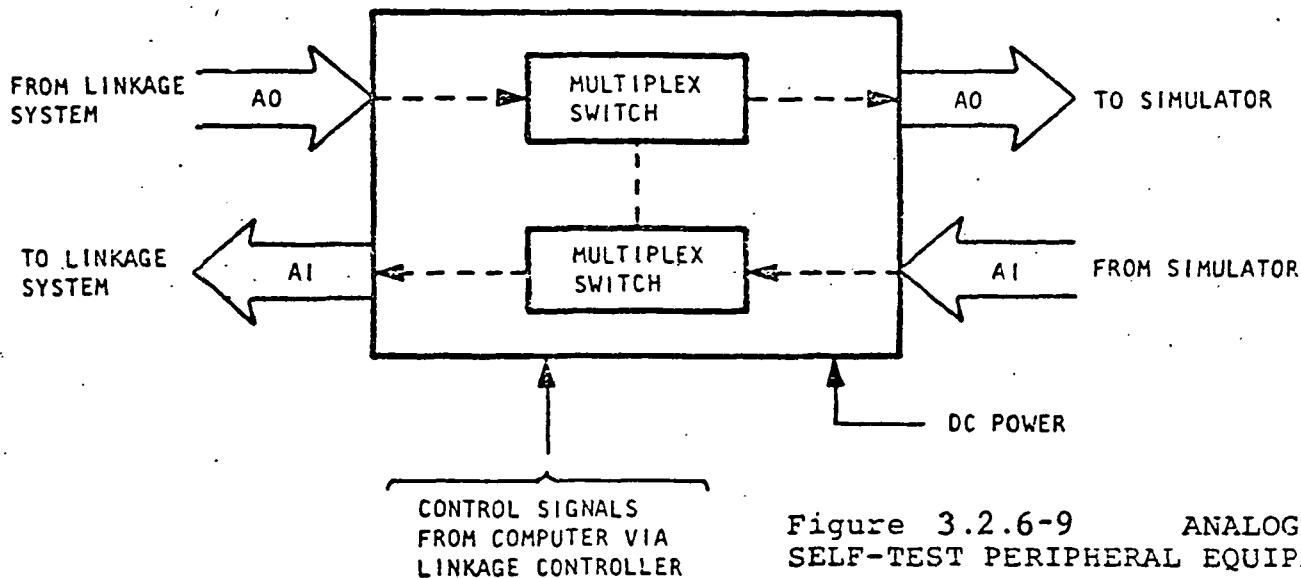
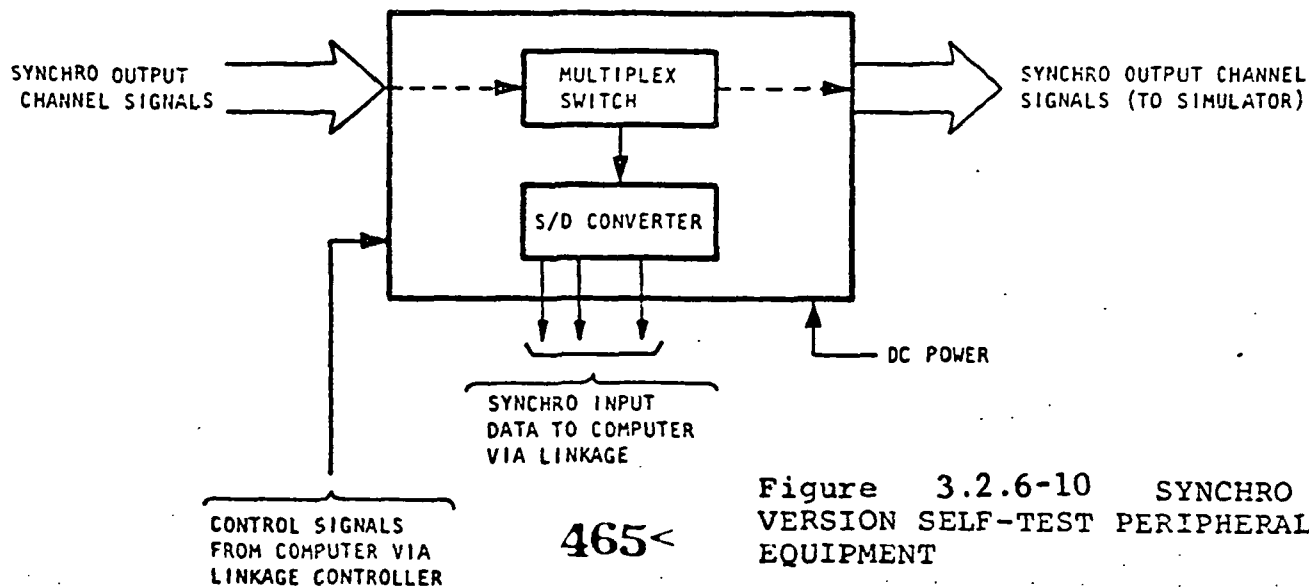
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Figure 3.2.6-8 DIGITAL I/O  
SELF-TEST PERIPHERAL EQUIPMENTFigure 3.2.6-9 ANALOG I/O  
SELF-TEST PERIPHERAL EQUIPMENTFigure 3.2.6-10 SYNCHRO CON-  
VERSION SELF-TEST PERIPHERAL  
EQUIPMENT

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### 3.2.7 Visual Systems (TBD)

The Visual System for the MBCS is not included in the scope of this study report.

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3.2.8 Miscellaneous Hardware

None required.

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### 3.2.9 Motion System

The mission modes requiring motion simulations are launch, launch aborts, re-entry, approach & landing, and the ferry operations. Orbital mission phases are conducted in a zero "g" environment except for brief thrusting maneuvers and therefore will not require motion cues. The motion cues for orbital thrusting maneuvers could be simulated. However, safety precautions would have to be taken to ensure that all crew members are strapped down which may impart negative training. Thus it is envisioned that no motion cues will be provided during orbital flight even though the capability exists. Motion requirements studies have concluded that five degrees of freedom are required for the SMS and that the performance capabilities of most state-of-the-art six degree of freedom motion systems are adequate to provide the motion cues required except for the vertical attitude required for launch and launch aborts. The payload capability required for the SMS is very large, as will be discussed below, and this factor influenced the selection of a six degree of freedom system since the payload capability for state-of-the-art six degree of freedom motion systems is greater than five degree of freedom systems.

During the requirements phase of this study, the Crew Station, Visual System and Motion System interface was identified to be a critical factor in the design of the SMS. As a result, a conceptual design/trade study was conducted which looked at numerous SMS configurations. These studies are documented in the "SMS Training Requirements Report."

NASA/Singer design reviews and meetings resulted in direction to proceed with the present SMS configuration. The significant conclusion reached was that a complete crew station and visual system with the tilt capability could not be mounted on a contemporary motion system due to payload considerations. The study also concluded that a floor mounted system is more desirable than a suspended system due to the anticipated large size of the visual system and the resulting restriction of angular excursions permissible. The Singer 48" and 60" stroke motion systems were utilized in the analysis since the payload capabilities of these machines were known and equalled or exceeded the published payload capabilities of other floor mounted systems. The sixty inch system proved to be better able to handle the anticipated loads and was selected as the recommended motion system. The remainder of this section describes the characteristics of the Singer sixty inch synergistic motion system and the modifications required to satisfy the SMS application.

### 3.2.9.1 Baseline Configuration

As shown on Figure 3.2.9-1, the baseline configuration consists of a crew station which extends aft to Sta. 573 (reference NR drawing VL70-003268) permitting authentic location of the Mission Specialist and Payload Specialist seats. The stations of these crew members will be simulated to a minimum extent. The only functional indicators and displays will be those associated with aero-

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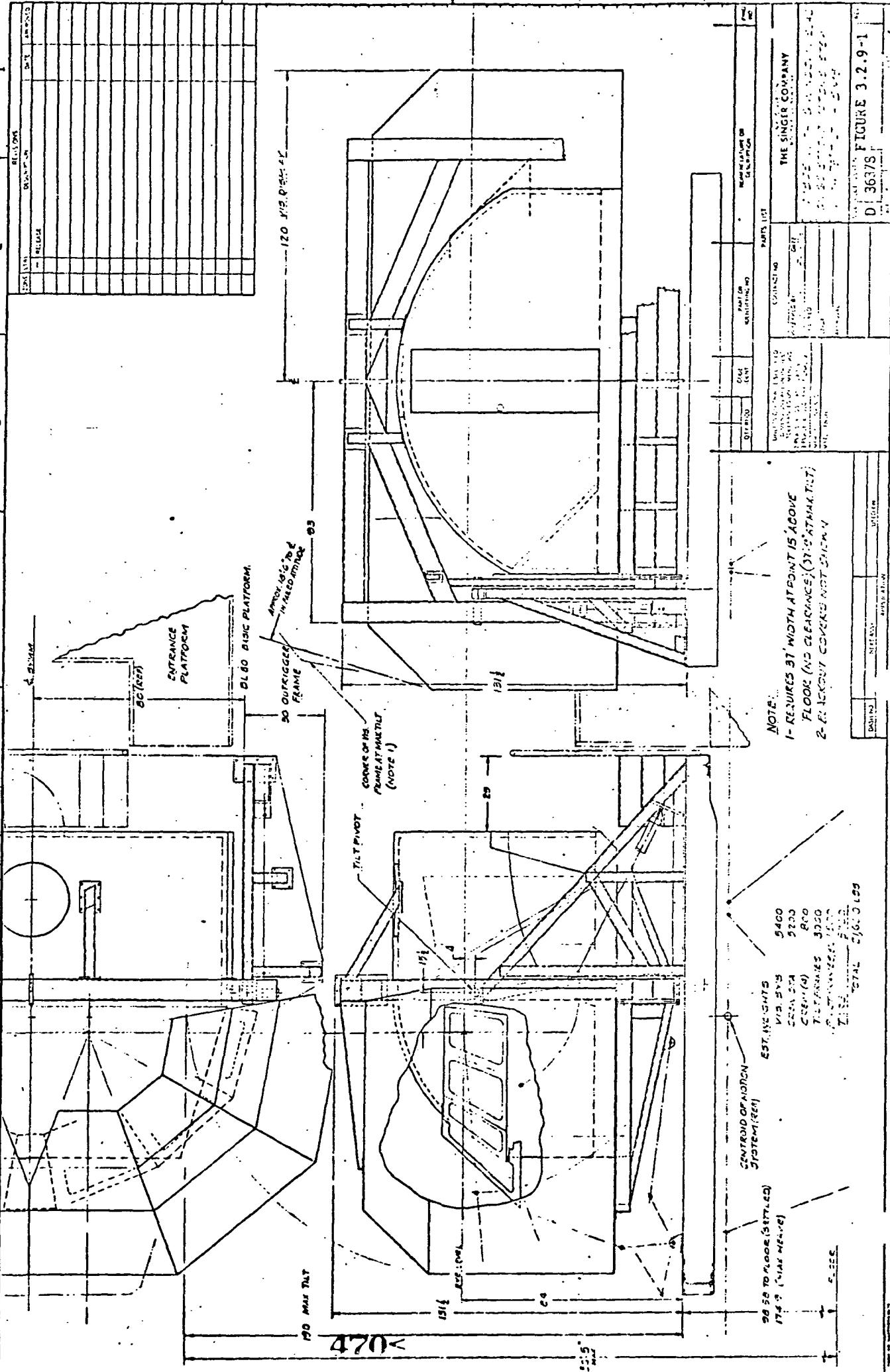
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dynamic flight operations. This configuration permits 75 degrees of tilt in addition to the basic motion system. The crew station extension of 35 inches to accommodate authentic aft seat locations requires raising the tilt pivot approximately 36" above the pivot in the configuration of paragraph 3.2.9.1.2. The estimated gross weight is approximately 20,160 lbs. and the moment of inertia in pitch is approximately 52,000 slug-ft<sup>2</sup>. This moment of inertia, approximately 40% higher than that for which the motion systems have been tested, renders the 48" stroke motion system less desirable for this concept since the joint and leg loading on the small stroke system is higher than that encountered on the 60" stroke system for the same payload.

3.2.9-5

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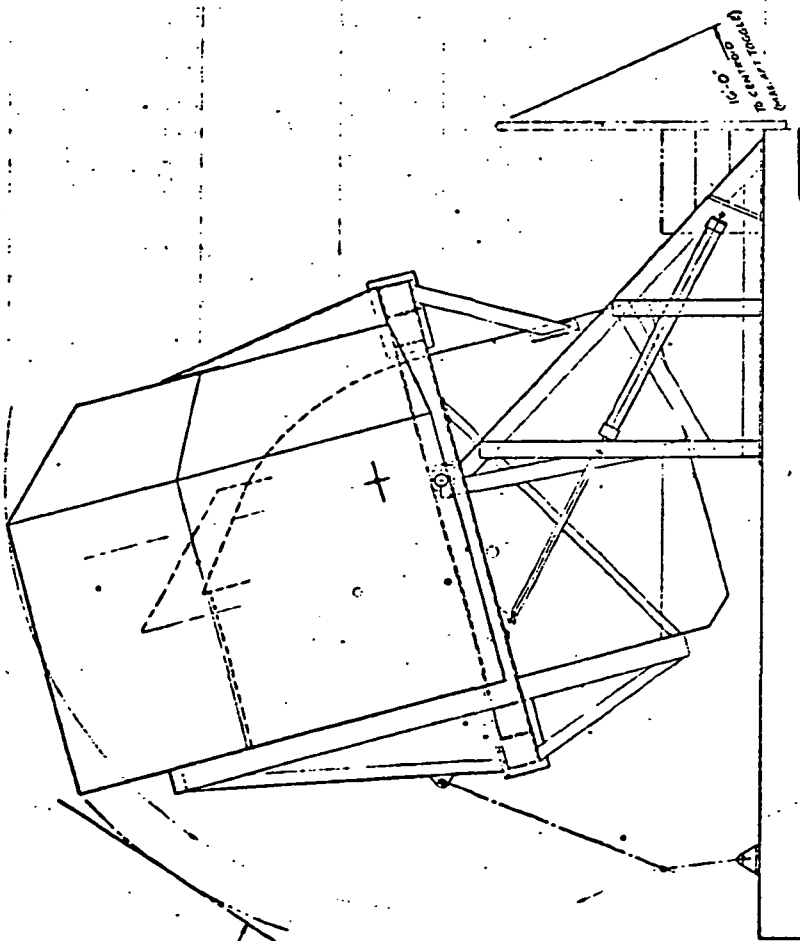
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| ITEM NO. | DESCRIPTION | QTY | UNIT |
|----------|-------------|-----|------|
| 1        | BASE        | 1   | EA   |
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| 99       | BRACKET     | 1   | EA   |
| 100      | BRACKET     | 1   | EA   |

APPROX. 18" TO 10" IN  
IN PAIRED ATTITUDE  
(MAX. WIDTH)



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CENTROID OF  
ACTION SYSTEM

|                    |  |                |  |
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| DECLASSIFIED BY    |  | DATE           |  |
| REVIEWED BY        |  | DATE           |  |
| APPROVED BY        |  | DATE           |  |
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| THE SINGER COMPANY |  | FIGURE 3.2.9-2 |  |
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This significantly higher moment of inertia warrants testing of the larger motion system even though analytical calculations indicate loads comparable to those already tested and operational.

An outline of the Crew Station is shown in Figure 3.2.1-1.

This payload will be mounted on a 60 inch stroke standard motion system with potentially modest changes desired due to the increased moment of inertia. In addition, a redundant leg system is recommended to enhance the safety of the basic system and add redundancy to the deceleration devices of the basic system.

A removeable instructor/operator station will also be required which will be centered in and as close as possible to the C/P center console.

Any relief on the aft seating requirements which permits shortening the crew compartment will be desirable since it would-

- 1) reduce the total load and enhance the growth capability
- 2) lower the tilt pivot location and thus relieve the loads on the tilt structure and the total moments of inertia.
- 3) reduce the required ceiling height which is a function of the height of the tilt pivot.



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### 3.2.9.2 Singer 60" Six Degree of Freedom Motion System

A description of the capabilities of the Singer 60" Motion System and its application and modifications required for MBCS use will be described in the following sections.

The Singer six-degree-of-freedom motion system (Figure 3.2.9-3) provides independent motion in six degrees of freedom. This capability is achieved by simultaneous operation of six linear hydraulic actuators arranged in three bipod pairs, as shown in Figure 3.2.9-4. The hydraulic system driving the actuators has sufficient power and capacity to provide appropriate positional and acceleration cues while supporting payloads specified herein.

The six-degree-of-freedom motion system is synergistic. That is, the activation of all six hydraulic actuators is generally required for motion in any degree of freedom. The 60-inch stroke motion system was successfully utilized on various 747, DC-10, and L-1011 simulators and NASA research projects, and is shown in Figure 3.2.9-5.

The following sections describe the motion system capabilities, operation, safety features, and mechanical and hydraulic design features.

#### 3.2.9.2.1 Mechanical Configuration

The basic mechanical configuration of the motion system is shown in Figure 3.2.9-4. The basic system consists of six independent hydraulic servo actuators, each controlled by a three-way servo valve.

The actuators are arranged in pairs to form bipods at the floor frame. The piston rod ends of each of the actuators attach to

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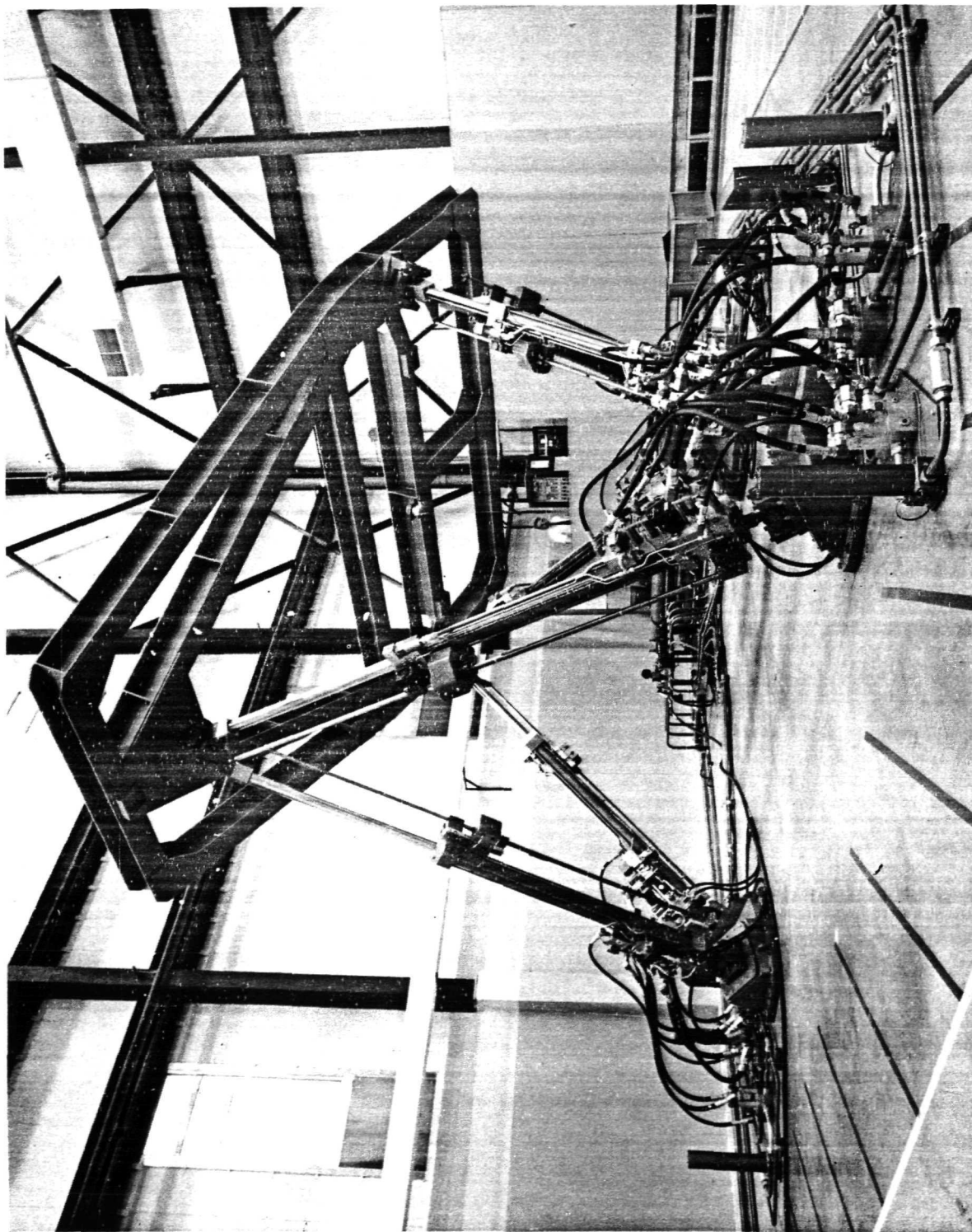


Figure 3.2.9-3 SINGER 60" SIX-DEGREE-OF-FREEDOM MOTION SYSTEM

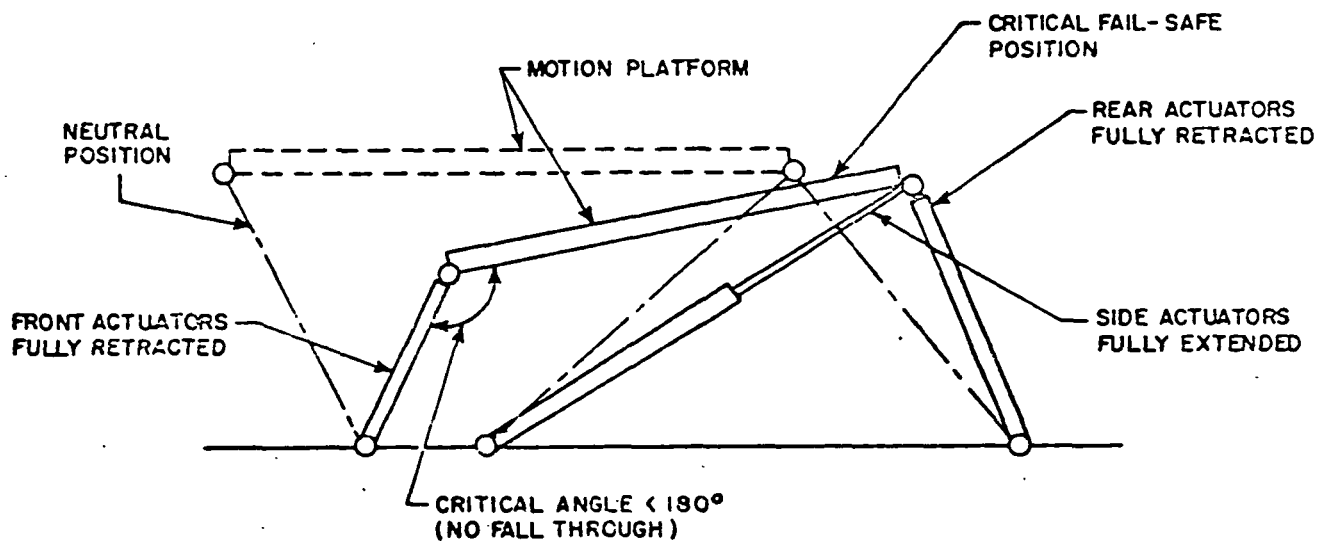
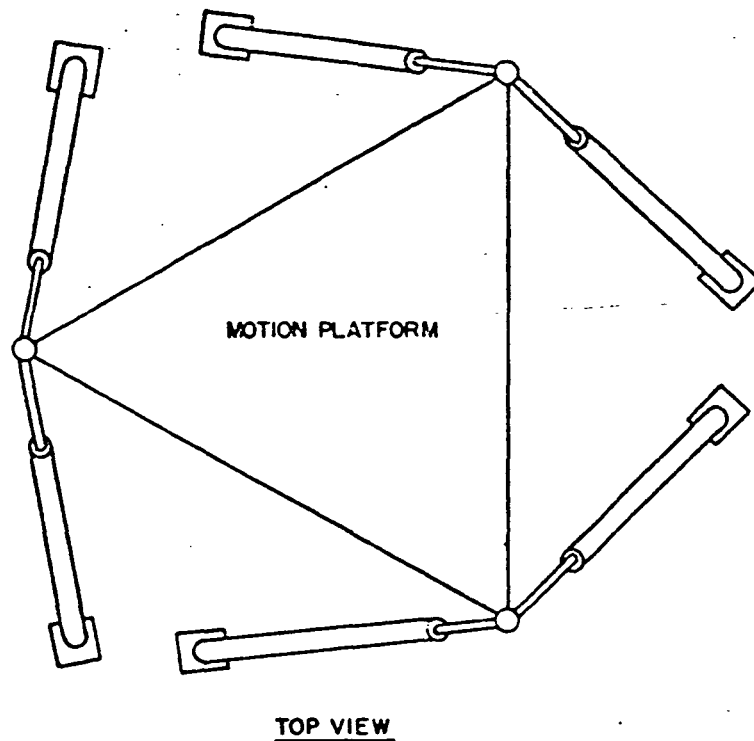


Figure 3.2.9-4 MOTION SYSTEM BIPOD CONFIGURATION (FAIL-SAFE)

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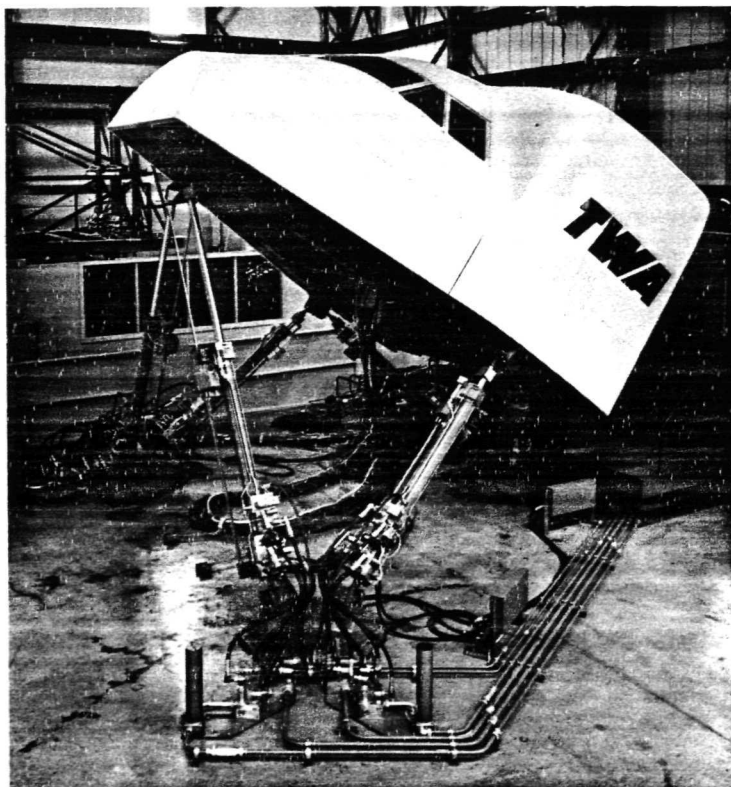


Figure 3.2.9-5 TWA 747 SIMULATOR SHOWING  
SIX-DEGREE MOTION SYSTEM

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a ball-joint-type universal fitting on the frame. This joint is shown in Figure 3.2.9-6. Two actuators attach to each of the three universal fitting assemblies. The bottom end of each actuator attaches through a two-rotational-degree-of-freedom gimbal fitting assembly to the floor. This joint is shown in Figure 3.2.9-7.

#### 3.2.9.2.2 Fail-Safe Configuration

The mechanical fail-safe aspect of the design is also illustrated in Figure 3.2.9-4, which shows a plan and two side elevations of the floor-mounted actuators and the motion platform. The motion system in its neutral position is shown in the side view by the broken-line drawing. The solid-line drawing shows the motion system in an orientation in which the rear actuators are fully retracted, the side actuators are fully extended, and the front actuators are fully retracted. The basic principle demonstrated is that by canting the plane of the bipods, the relative angles between each bipod and the motion platform can be restricted, thereby preventing fall-through and reducing the maximum loads imposed on the actuators. The configuration has been optimized to allow maximum excursions with a minimum of power. Figure 3.2.9-8 also presents a plan and side views of the motion system, and shows the motion platform position with the actuators fully retracted (the "settled" position), at approximately mid-travel (the "neutral" position), and fully extended.

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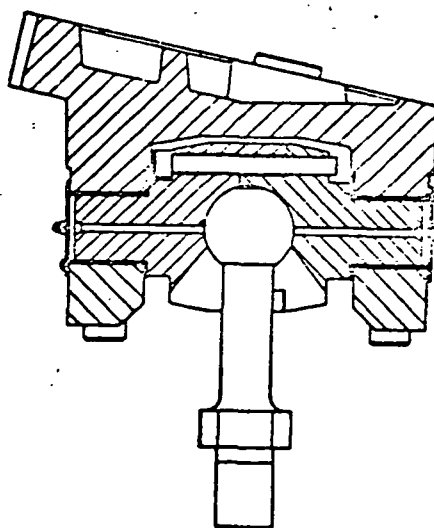
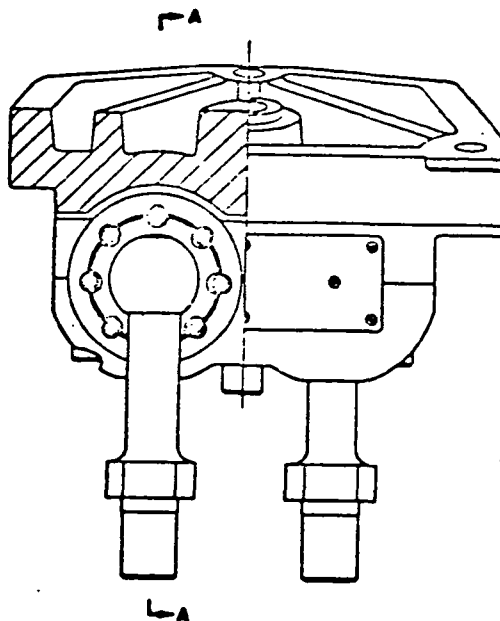
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SECTION A-A

Figure 3.2.9- 6 UPPER BALL-TYPE  
UNIVERSAL JOINT

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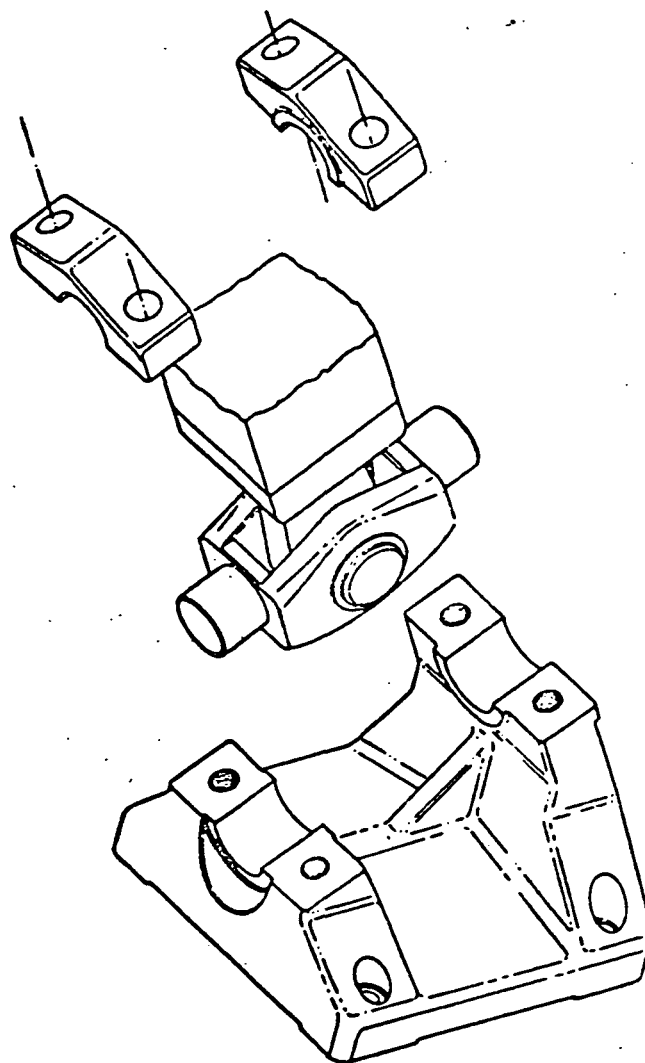


Figure 3.2.9- 7 LOWER GIMBAL-  
TYPE JOINT

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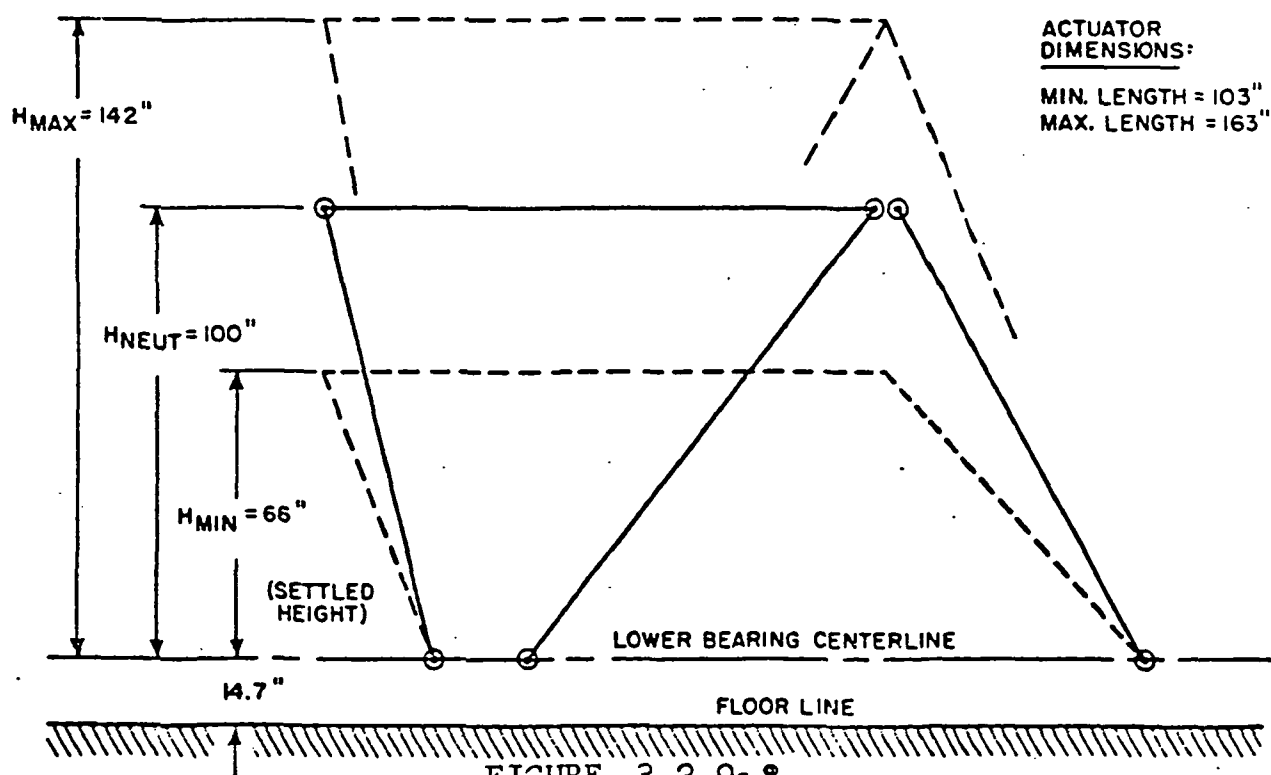
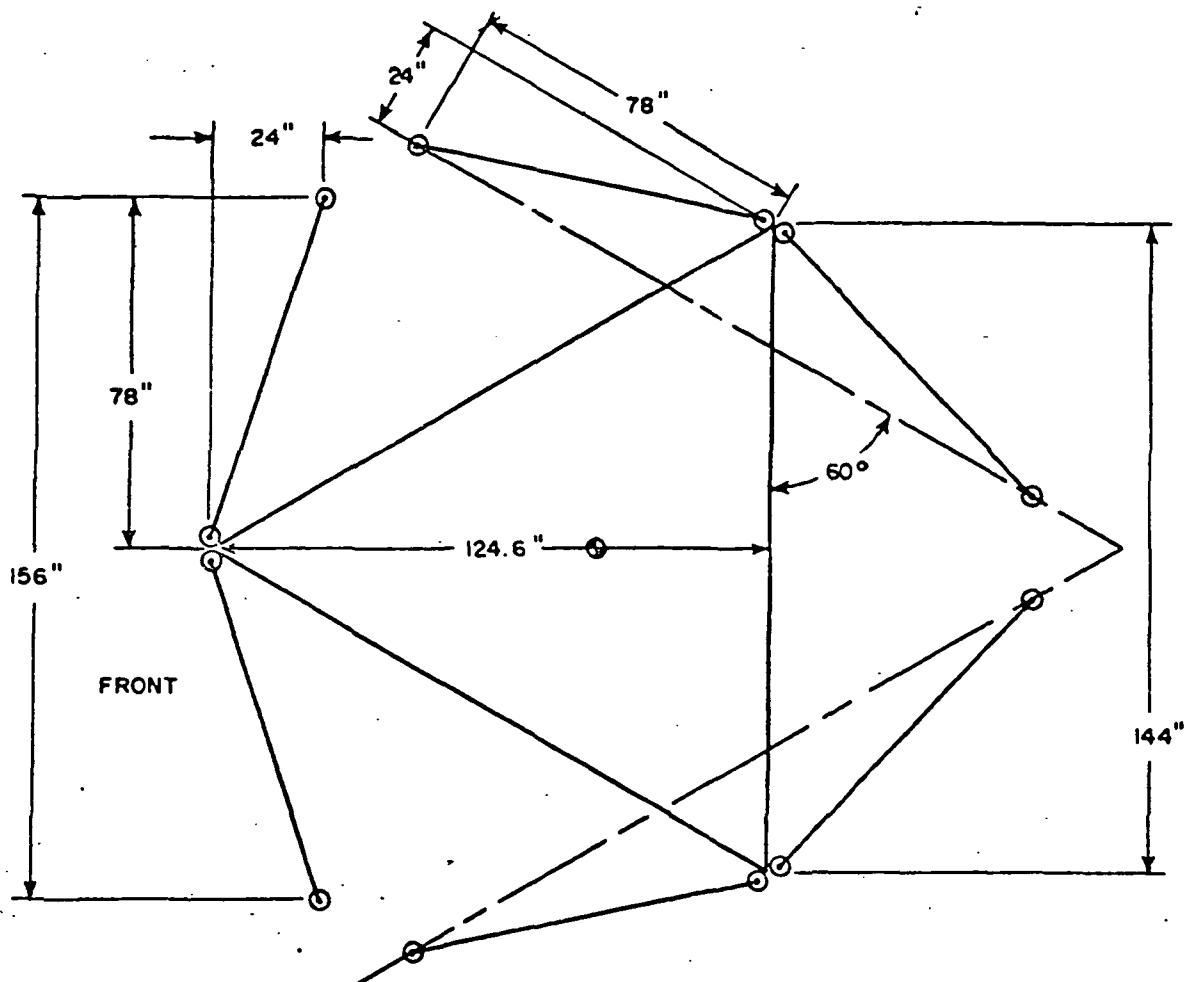


FIGURE 3.2.9-8  
MOTION SYSTEM IN NEUTRAL, SETTLED, AND RAISED POSITIONS



### 3.2.9.2.3 Motion System Capabilities

The normal limits of performance of the 60 inch stroke motion system in each degree of freedom, operating from the normal "neutral" position, are as follows (all values measured at the motion platform):

#### 1) Pitch

- a) Rotation: \* +30, -20 degrees
- b) Velocity:  $\pm 15$  degrees/second
- c) Acceleration:  $\pm 50$  degrees/second/second

\* With a shift of the centroid position it is possible to obtain pitch angles of  $+34\frac{1}{2}^{\circ}$  and  $-30^{\circ}$  within operational limits of the actuators.

#### 2) Roll

- a) Rotation:  $\pm 22$  degrees
- b) Velocity:  $\pm 15$  degrees/second
- c) Acceleration:  $\pm 50$  degrees/second/second

#### 3) Yaw

- a) Rotation:  $\pm 32$  degrees
- b) Velocity:  $\pm 15$  degrees/second
- c) Acceleration:  $\pm 50$  degrees/second/second

#### 4) Vertical

- a) Translation: up to 39 inches, down 30 inches
- b) Velocity:  $\pm 24$  inches/second
- c) Acceleration:  $\pm 0.8$  g

5) Lateral

- a) Translation: 48 inches right and left
- b) Velocity:  $\pm 24$  inches/second
- c) Acceleration:  $\pm 0.6$  g

6) Longitudinal

- a) Translation: Forward 48, aft 48 inches
- b) Velocity:  $\pm 24$  inches/second
- c) Acceleration:  $\pm 0.6$  g

Excursion capabilities when the crew station is pitched to the vertical position are as follows:

| <u>Degree of Freedom</u> | <u>Displacement</u>    |
|--------------------------|------------------------|
| Roll                     | $\pm 12^\circ$         |
| Pitch                    | $+15^\circ, -35^\circ$ |
| Yaw                      | $\pm 15^\circ$         |
| Heave                    | $\pm 15''$             |
| Lateral                  | $\pm 25''$             |
| Longitudinal             | $+20'', -40''$         |

These figures reflect the maximum programmed values for normal operation with a payload of 23,000 lbs., with the C.G. approximately 62" above and 6½" aft of the centroid of the upper joint patterns and inertial loads about the centroid of:

$$I_{xx} = 33,000 \text{ slug-feet}^2$$

$$I_{yy} = 37,000 \text{ slug-feet}^2$$

$$I_{zz} = 19,000 \text{ slug-feet}^2$$

The listed performance is well within the motion system capability in both velocity and acceleration.

The simultaneous capabilities of the motion system may be defined in an infinite number of ways, since the system has the ability to trade off motion capabilities from one degree of freedom to another.

#### 3.2.9.2.4 SMS Loading and Weights

The motion based SMS payload is estimated at 21,660 lbs. with a C.G. (in the tilted attitude) approximately 84" above and 8" forward

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of the centroid. The new moments of inertia about the centroid are approximately as follows:

$$I_{xx} = 49,435 \text{ slug-feet}^2$$

$$I_{yy} = 62,454 \text{ slug-feet}^2$$

$$I_{zz} = 18,874 \text{ slug-feet}^2$$

A static and dynamic analysis was performed for one of the most severe attitudes possible for the 6 D.O.F. 60" stroke motion system for the design load anticipated for the SMS and compared with the same static and dynamic condition with the Std. Design Load. The results are as follows:

|                        | <u>Std. Des. Load</u>       | <u>SMS</u>                  |
|------------------------|-----------------------------|-----------------------------|
| Weight                 | 23,000#                     | 21,660#                     |
| I X-X (about centroid) | 37,000 slug ft <sup>2</sup> | 49,435 slug ft <sup>2</sup> |
| <u>C.G. Location</u>   |                             |                             |
| Above centroid         | 62"                         | 84"                         |
| Aft of centroid        | 6½"                         | (8" Fwd)                    |
| <u>Actuator Loads</u>  |                             |                             |
| Fwd Toggle Pos.        |                             |                             |
| Fwd Legs (true static) | 9.38K                       | 12.3K                       |
| Fwd Legs (true dyn.)   | 5.41K                       | 8.1K                        |
| Aft Legs (true static) | 5.1K (tension)              | 7.65K (T)                   |
| Aft Legs (true dyn.)   | 13K (T)                     | 14.8K (T)                   |

The increase in loading appears sufficiently great to warrant a test program to verify satisfactory operation of the motion system and

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to determine the modifications necessary to preclude damage to the visual systems if such modifications are deemed essential.

The SMS payload weights and loads were based on the following estimates.

Motion System Payload (pounds):

|                    |              |
|--------------------|--------------|
| Cockpit and Cables | 5,200        |
| Personnel (4)      | 800          |
| Visual Display     | <u>5,400</u> |
| Total Payload      | 11,400       |

Total Weight on the Floor (pounds):

|   |              |
|---|--------------|
| Payload                                     | 11,400       |
| Tilt Frames & Mechanism                     | 3,000        |
| Tilt Pivot Frame & Yaw Stabilizer           | 1,500        |
| Tare (platform, upper joints and actuators) | 5,760        |
| Lower Actuators (6)                         | 1,980        |
| Base Assembly (3)                           | 6,000        |
| Redundant Leg Assemblies                    | 5,100        |
| Hydraulic Lines                             | <u>3,000</u> |
| Total Floor Weight                          | 37,740       |

Worst-Case Dynamic Load (pounds)  
Because of Maximum Acceleration  
Capability of Motion:

|             |        |
|-------------|--------|
| Compression | 46,000 |
| Tension     | 30,000 |
| Shear       | 31,000 |

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Maximum dynamic loads do not occur on every pad at any given instance. Values given are for the most heavily loaded pad. (The area of each floor pad is 5,000 square inches.)

#### 3.2.9.2.5 Motion System Performance

Depending on the particular flight program, the motion system is capable of responding to computer input signals as noted in the following examples.

##### 3.2.9.2.5.1 Ground Conditions

The motion system is capable of providing the indications appropriate to motion of the aircraft on apron, taxiway, and runway. The motion will be a random, low-frequency, low-amplitude, multi-directional oscillation with reasonably abrupt application. The computations could enable varying the amplitude of oscillation to reproduce the irregularities of unimproved or unprepared surfaces. The system will reproduce the longitudinal effects due to abrupt brake applications, rejected takeoffs and the lateral effects due to asymmetric braking, asymmetric thrust, or loss of directional control on icy runways.

##### 3.2.9.2.5.2 Takeoff and Landing

During the takeoff roll, the ground performance of the motion system will be as described in the previous subsection. Transition to flight will be indicated by abrupt cessation of the random oscillation. The motion system will provide the correct indications of takeoff rotation and will maintain a nose-up attitude appropriate to the climb-out.

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Appropriate longitudinal effects will occur as a result of changes in thrust, retraction of landing gear, and retraction of high-lift devices. Similar effects will be reproduced during the landing phase, where gear extension and lift and drag-inducing extension will cause appropriate longitudinal, vertical, and low-frequency vibration effects to occur in the motion system. The motion system will correctly reproduce the landing impact according to the existing aircraft attitude and vertical and sideslip velocities and, where the vertical momentum is greater than the absorption capabilities of the shock absorbers, landing bounce will be simulated.

Pitching and rolling effects of single truck contacts will be correctly reproduced, and the magnitude of the bounce will be dependent on the current landing weight. The longitudinal and pitching effects of brake application will be correctly simulated. Mishandling of the brakes during rollout under poor runway conditions will cause lateral effects associated with skidding where appropriate.

For an aborted landing, the motion simulated will be similar to a normal landing in the initial stages, followed by rotation, increase in thrust, and climbing associated with takeoff simulation.

The longitudinal motion and ground effects associated with effective braking and deceleration will be simulated for an aborted takeoff.

The effects of thrust, altitude, and attitude changes in a missed approach will also be simulated. The motion system will be capable of simulating the more complex combinations of motion cues associated with the circling approach and landing maneuver.

#### 3.2.9.2.5.3 Normal Flight

A thorough exercise of the motion system capabilities will be necessary to simulate the complex and repeated cues occurring during airwork maneuvering. By virtue of the capability of the motion system to move in six degrees of freedom, and to provide cues correct in direction and proportional in magnitude to the Orbiter acceleration, all the maneuvers associated with airwork will be simulated correctly.

The introduction of varying degrees of turbulence will produce the appropriate motion effects of severe pitch and roll, rapid climb or descent, and above-placard speed.

Superimposed upon the background motion, the motion system will provide the characteristic periodic oscillations of the Orbiter such as the phugoid oscillation, short-period oscillations, and lateral instability, and will also simulate characteristic Orbiter vibrations up to 5 cycles per second.

#### 3.2.9.2.5.4 Abnormal Flight

The motion system will be capable of correctly reproducing the effects of the stall, such as stall buffet (up to 5 cycles per second), pitch down, and wing droop under asymmetric conditions.



The lateral motion and roll effects of an engine failure, during takeoff and normal flight, will be simulated, including the adverse effect of momentary incorrect rudder input, as well as conditions appropriate to yaw damper, autopilot, Mach trim failure, or hydraulic failure resulting in asymmetric control configurations. High-speed characteristics, such as Mach buffet and trim changes, will cause appropriate effects in the motion system.

#### 3.2.9.2.6 Actuator Servo Control Loop

The motion system hydraulic actuator is connected in a regenerative-type hydraulic system configuration. The rod side of the actuator is connected directly to the hydraulic power supply, and flow to or from the ram side of the actuator is controlled by a three-way servo valve.

In order to provide the most realistic simulation of motion cues, a rapid, smooth, nonhunting response to all input signals is desirable. This is assured with the control system design by the tightly compensated servo-loop used in the hydraulic system. Further, the design ensures that the overall system resonant frequency is large compared with both normal operating and buffet frequencies, and thus avoids the possibility of exciting resonance with higher frequency components of servo-control input signals. The normal operating bandwidth is sufficiently wide to be compatible with the bandwidth of servo-control input signals.

### 3.2.9.2.7 Motion System Hydraulics (See Section 3.2.9.2.11)

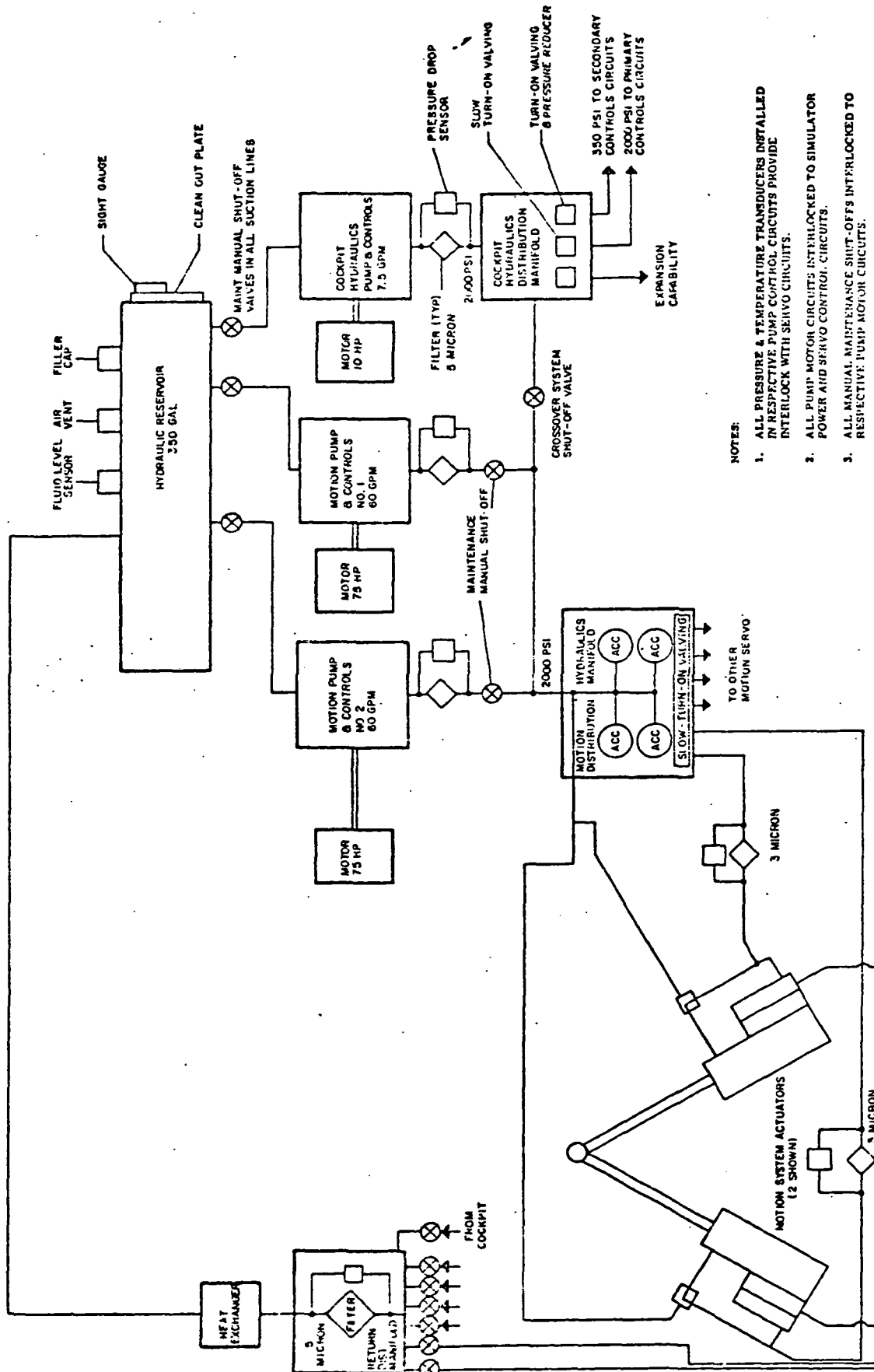
In order to determine the hydraulic flow requirements, several duty cycles representative of worst-case maneuvers were defined. The hydraulic pumps were sized to provide full average flow required for these maneuvers, with peak demands supplied from accumulators. These accumulators are recharged during that part of the maneuver when actuator flow demand is below pump capacity, enabling the system to respond without performance degradation. This can be achieved with two 60-gpm pumps, as illustrated in Figure 3.2.9-9.

### 3.2.9.2.8 Motion System Controls

#### 3.2.9.2.8.1 Ingress and Egress

For boarding purposes, the motion system is deactivated using controls described in Section 3.2.9.2.8.2. The motion system then returns smoothly to the settled position, shown in Figure 3.2.9-8 and the access platform can be raised to allow entrance to or exit from the flight compartment.

Note that the return to the "settled" or "at rest" static position is the eventual result of electrical or hydraulic shutdown at any time because the design configuration maintains compressive loads in all actuators. The inherent stability of the motion system thus obviates the necessity for external means of forcing normal return to the settled position or providing locking devices for maintaining the position.



## NOTES:

1. ALL PRESSURE & TEMPERATURE TRANSDUCERS INSTALLED IN RESPECTIVE PUMP CONTROL CIRCUITS PROVIDE INTERLOCK WITH SERVO CIRCUITS.
2. ALL PUMP MOTOR CIRCUITS INTERLOCKED TO SIMULATOR POWER AND SERVO CONTROL CIRCUITS.
3. ALL MANUAL MAINTENANCE SHUT-OFFS INTERLOCKED TO RESPECTIVE PUMP MOTOR CIRCUITS.
4. ALL P PICKUPS ON FILTERS PROVIDE READ OUT AT HYDRAULIC MAINTENANCE CONTROL PANEL.
5. ALL PRESSURE TRANSDUCER PICK-UPS PROVIDE REMOTE READING OF HYDRAULIC PRESSURE AT MAINTENANCE CONTROL PANEL.
6. COCKPIT HYDRAULIC POWER MAY BE OBTAINED FROM MOTION CIRCUITS BY ACTIVATING CROSS OVER SYSTEM VALVE.

FIGURE 3.2.9-9  
MOTION SYSTEM HYDRAULICS

### 3.2.9.2.8.2 Activation and Deactivation

The motion system deactivation logic circuitry ensures that the motion system comes to rest in a full-down "at rest" position. A master maintenance control, located on the electronics cabinet, is provided to ensure that the motion system is always deactivated when maintenance personnel are inside the motion structure.

### 3.2.9.2.8.3 Emergency Deactivation

Activation of the "emergency stop" switch, at the maintenance panel, results in complete shutdown of the entire system and, as such, is only used for rapid deactivation of the motion system (in preference to the normal deactivation controls) under extreme conditions. In this case, a command is provided to a quick-settle control valve for returning the motion system to the settle position from any attitude at the highest practicable speed. The quick emergency settle rate of the cylinder piston is approximately 4 inches per second. The normal rate is approximately 3 inches per second. The access platform

risers to meet the motion system under the power of a reserve stored energy source. The design allows all personnel to safely egress to the service platform in 24 to 31 seconds, depending on the position of the cockpit at the time electrical power is cut off.

### 3.2.9.2.9 Safety Features

In addition to the activation and deactivation interlock features described in Section 3.2.9.2.8.2 and the quick-settle control

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described in Section 3.2.9.2.8.3, the following design features are incorporated with a view to increasing the safety aspects of the motion system.

Suitable protective devices are installed to protect personnel and equipment - i.e., to prevent bottoming of actuators because of the control valve inadvertently being driven to an end stop, and upon initial turn-on of the system (surge protection). Mechanical stops and independent dual electrical limit switches (See Section 3.2.9.2.9.1) are included in the motion system. Should a runaway type of failure occur, a shutdown feature automatically switches off the power to the motion system and returns the platform to the "at rest" position at a smooth controlled rate.

A loss in hydraulic pressure causes a shutdown of the system whether the pressure loss is intentional or accidental. Tracking error of significant magnitude between commanded and actual position is detected and an automatic shutdown is initiated. In the event of a malfunction of any reference power source, all circuits, power and servo-control, are suitably interlocked to terminate motion by a complete system shutdown.

The following devices and techniques provide for the safe operation of the motion system.

#### 3.2.9.2.9.1 Limit Sensing

Limit switches are provided to sense travel of the actuators beyond the servo electronic limits. Two sets of limit switches on each

servo actuator are provided: one set provides velocity attenuation in the event of a runaway servo; the other set provides for a complete shutdown of the motion system. In this situation, the motion system returns to its "at rest" position at a smoothly controlled rate.

#### 3.2.9.2.9.2 Velocity Control

In addition to the velocity attenuation noted in 4.1.2.9.1, both internal flow control and external cylinder piston velocity buffer controls are provided to mechanically control both maximum velocity and the rate of piston deceleration if all other safety features fail. The buffers are cam-operated-type deceleration valves, actuated by a rod driven from the piston rod, and provide a controlled rate of change of piston speed as the actuator piston approaches its end of stroke.

Relief valves are provided to limit the maximum force that may be generated by the actuator and are the fast-acting mechanical/hydraulic sensing type. These relief valves are on the servo actuator to provide complete protection regardless of actuator position.

Slow-turn-on hydraulic valving is provided to preclude shocks from being transmitted during motion turn-on (surge control) and turn-off.

#### 3.2.9.2.9.3 Crush Pads

Maximum dynamic load protection is provided through the utilization of a special, honeycom-pad device incorporated in the lower joint assembly. The shock pad is captivated and implemented in a manner

to provide for both tensile and compressive loading protection.

Lower joint assembly floor pads are designed to limit floor loading to a value under 100 psi for the worst-case dynamic loading. This value of loading allows the use of normal-mix reinforced concrete as used throughout the construction industry. The worst-case dynamic loads are transient loads, generally present only during the period when the motion system is undergoing a maximum acceleration and generally sustained for a period of 30 milliseconds or less.

The base pads are designed to be lagged to a concrete floor using commercially available lag inserts.

#### 3.2.9.2.9.4 Universal Joints (See Figure 3.2.9-6 and 3.2.9-7)

To provide structural integrity and safety in the design of the motion actuator attachments, universal joints are utilized at each end of the actuator. These joints are designed for a minimum yield strength factor of 4.0 times the maximum dynamic load factor which can be encountered at the joint by the operation of the motion system. The breaking strength of this joint provides for an ultimate safety factor of 6.0. The maximum dynamic load is calculated on the basis of a complete failure of all safety systems used in the motion system.

Compressive loading of the joints under maximum programmed acceleration of the motion system provides for a safety factor of 7.7 times the minimum yield strength. This factor, combined with the use of high-film-strength lubrication on the sliding parts of the joints, ensures maximum reliability and longevity of performance of the joints.

#### 3.2.9.2.9.5 Hydraulic Actuators

Special design consideration is devoted to providing for maximum strength and reliability of the hydraulic actuator. Bearing loads and cylinder design insure maximum service life of the cylinder. The column strength of the actuator is such as to provide a minimum safety factor of 4 for the critical buckling load. A special rod seal leakage collector is provided to scavenge hydraulic leakage past the piston rod seal.

The load-carrying capability of the actuators is dependent upon both the static load requirements of positioning the cockpit system to its extremes of motion and the maximum acceleration capability of the actuator when positioned very close to its maximum extended length. It is at this position that the column strength of the actuator is the least. A minimum safety factor of 4 relative to this extreme situation has been provided in the design.

During operation of the motion system near its normal neutral position (at a 20-inch extension of the actuators), the safety factor for the column strength at worst maximum loading is 8.9.



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It is anticipated that the motion system will operate at or near the neutral position during 90% of its operating time. The normal maximum accelerations anticipated provide for a safety factor of 15.9 with all safety systems operational. The high safety factor in this region provides for maximum reliability, endurance, and maintenance-free operation of the actuators.

Consideration is given to the side loading at the piston rod bearing. This side loading results because of the cant of the actuator. The force vector normal to the bearing is dependent upon the static component of the actuator weight and its angle with the vertical, plus the dynamic transients that could be present because of failure-type step inputs from the computer. The maximum worst-case side load that can be experienced in the maximum failure mode at cant angle results in a bearing pressure of less than 70 psi. The controlled leakage past the piston rod seals also ensures good lubrication of the bearing. This lubrication and the low side loading of the actuator bearing ensure long life and maintenance-free operation of the actuators.

#### 3.2.9.2.9.6 Support Structure

Design of the motion system load-carrying support structure provides for a minimum safety factor of 4.0 times the yield strength of the materials used in the construction, based on the maximum dynamic load that may be encountered during the operation if all safety systems fail.

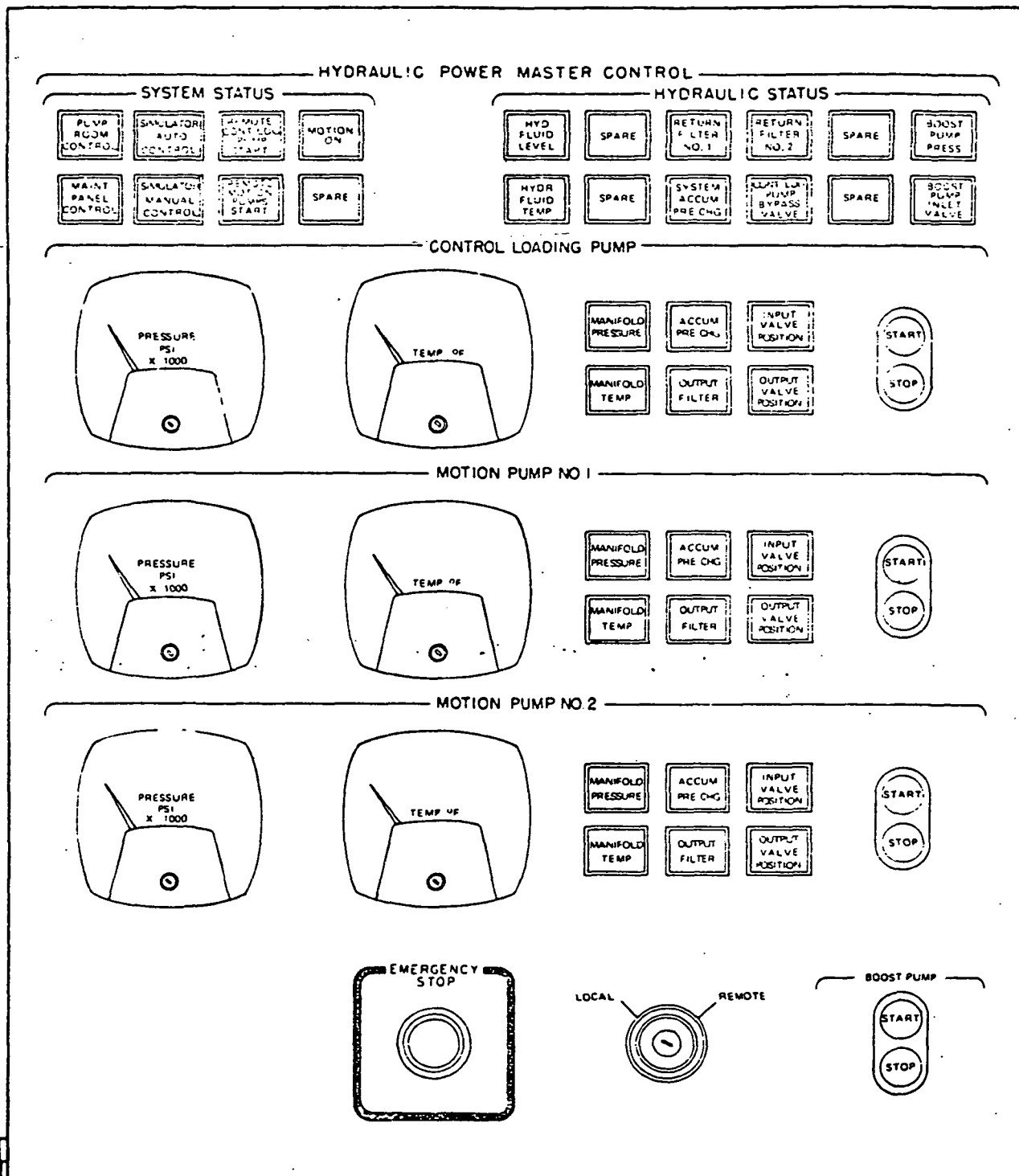
### 3.2.9.2.10 Maintenance Provisions

Ease of maintenance was a prime consideration in the design and construction of the motion system. For example, system transducers provide voltage outputs directly without the need of demodulators. Hydraulic fluid level indicators are clearly visible and system replenishment is easily accomplished. There are adequate provisions for bleeding and lubricating the system.

The hydraulic control panel shown in Figure 4.1.2-10 is provided as part of the hydraulic power system, with provisions for semi-automatic troubleshooting of the hydraulic power control system. This feature, which is implemented by the use of color-coded readout lights for strategic parts of the system, provide a go/no-go type of indication, thereby pinpointing the area of system malfunction. The panel is also provided with gauges to provide a continuous indication of the operation of the hydraulic system at all times.

Two cylinder change jacks are also provided along with jack receptacles on the motion platform to assist in changing a motion actuator assembly. The purpose of these jacks is to enable the load to be taken off the cylinder by support of the payload.

The Motion System Electronics Cabinet is of modular panel-type construction. The standard cabinet includes the Power Distribution Control Panel (Figure 3.2.9-11), the Motion System Maintenance Control Panel (Figure 3.2.9-12), the Cylinder Position Control Panel (Figure 3.2.9-13), and the Test Points Panel (Figure 3.2.9-14).



SPEAKER AND  
MICROPHONE  
JACKS

Figure 3.2.9-10

HYDRAULIC POWER SYSTEM MASTER CONTROL PANEL

The Power Panel provides the  $\pm 24$  VDC and +28 VDC power for the motion system. Circuit breaker protection for the input and output power is provided as well as switches for ON/OFF power control.

The Maintenance and Cylinder Position Control Panels are provided in the Motion System Electronics Cabinet for ease of maintenance and troubleshooting. They are equipped with controls and indicators for manual operation of the system, thereby isolating the computer inputs. The intention of this feature is to allow each servo to be checked operationally without removing the servos from the system or to allow operation of the system entirely through manual or analog means of control - i.e., off-line.

The Test Point Panel provides easily accessible test points of critical signals associated with each servo actuator.

#### 3.2.9.2.11 Hydraulic System

The hydraulic pump used to provide hydraulic power for the motion system is of the variable-displacement type and is remotely located in order to reduce noise level. At maximum displacement, the pumps provide a sufficient amount of fluid to meet circuit demands. The maximum pump pressure is at least 1.5 times the maximum working pressure of the system. The hydraulic system operates at 2,000 psi.

The hydraulic system block diagram is shown in Figure 3.2.9-9.

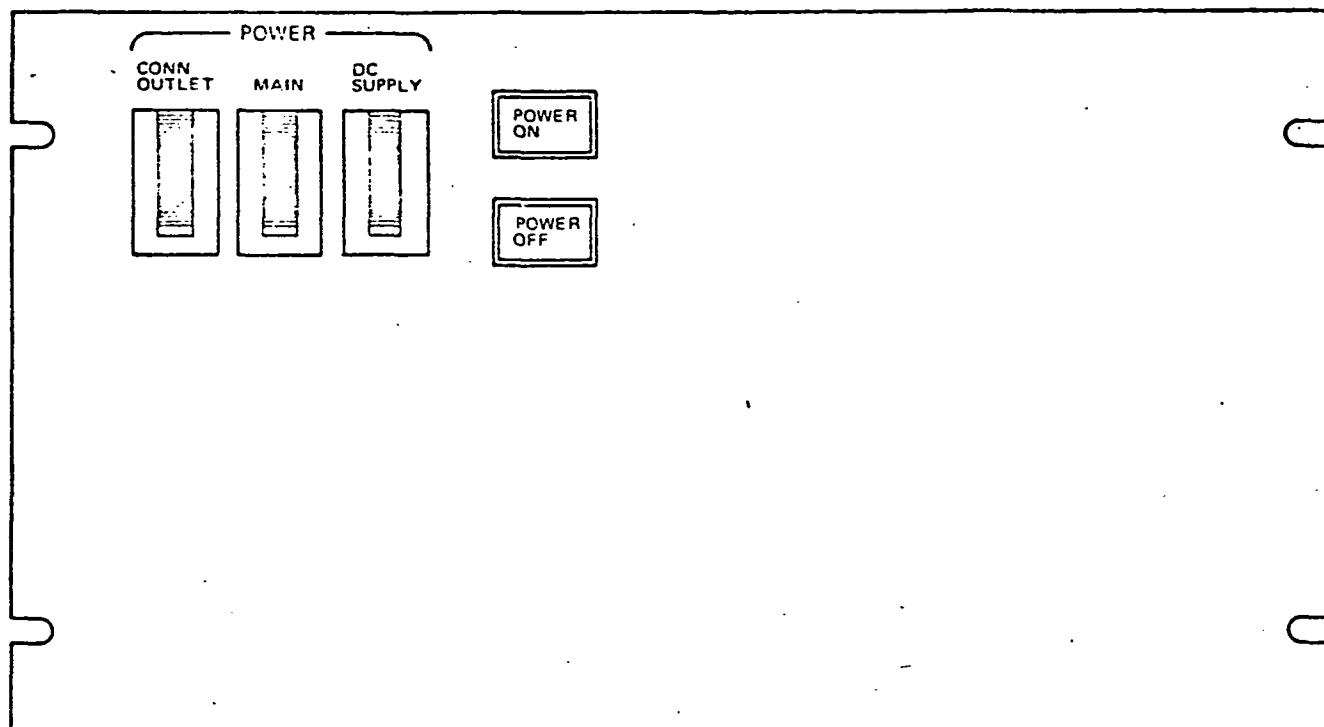


FIGURE 3.2.9-11  
POWER DISTRIBUTION CONTROL PANEL

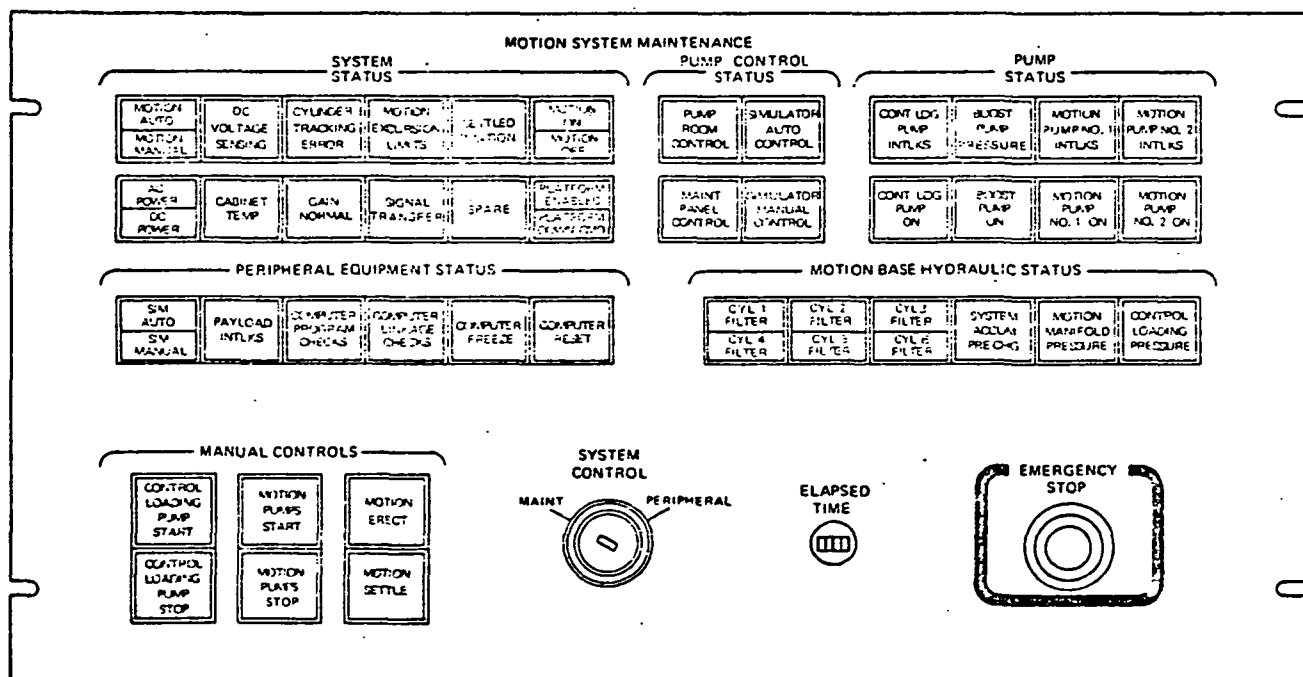


FIGURE 3.2.9-12  
MOTION SYSTEM MAINTENANCE CONTROL PANEL

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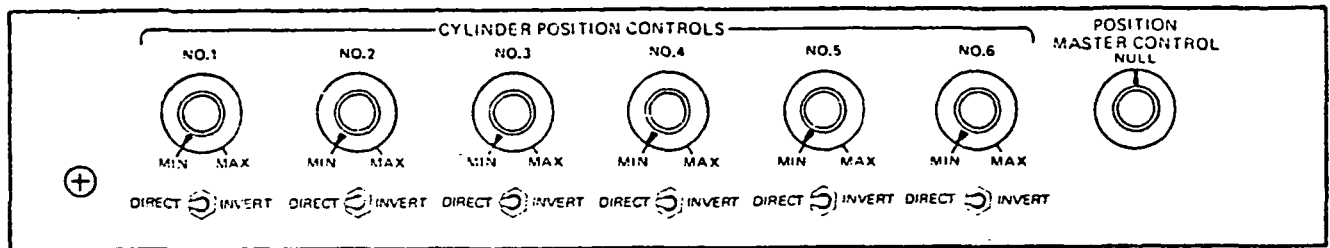
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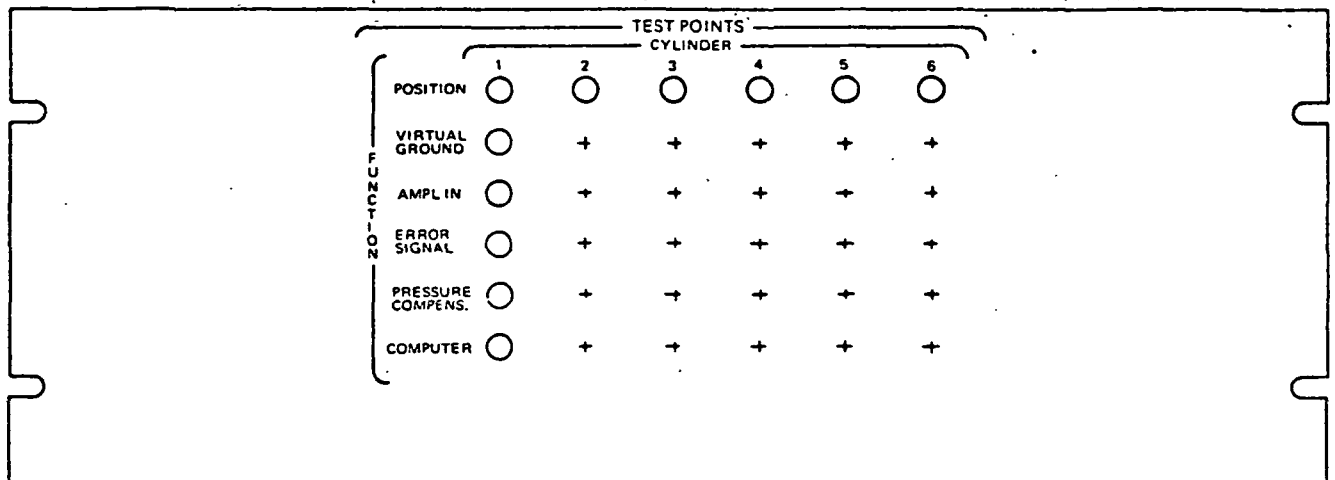
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FIGURE 3.2.9-13

CYLINDER POSITION CONTROL PANEL



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Figure 3.2.9-14

TEST POINTS PANEL

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The pumping system main pressure line is provided with a pressure gauge to indicate system pressure and an oil temperature gauge and automatic oil temperature monitoring system which shuts the pump down if the oil temperature exceeds a preset value. Accumulators of adequate capacity are used to compensate for line loss; a gas pressure gauge is provided with each accumulator. The hydraulic reservoir is of adequate capacity and is provided with a visual-type contents gauge and a device that automatically shuts down the system when the fluid level falls below a predetermined safe level. The reservoir is provided with a filtered air vent. Adequate provision is made for filling, draining, and cleaning the reservoir. A high-capacity filter of 3 microns nominal rating is installed in the return line to the reservoir. High-pressure filters of 3 microns nominal rating are installed immediately upstream of each servo valve. All fluid filters are provided with pressure-drop warning lights to indicate element contamination level. A pressure relief valve is provided and functions when the maximum operating pressure is exceeded by 100 psi. All pressure and temperature gauges and controls are mounted on a panel in the pump room. All connections to the panel are flexible to reduce vibration on the panel.

Steel tubing is used throughout the system except where moving components dictate flexible hoses. Adequate interlocks are provided for pressure loss, over-temperature, and excess flow protection.

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Pressure, temperature, quantity, and accumulator gauge readings are available and instrumented at the hydraulic control panel located centrally within the pump room. All hydraulic filter warning lights are displayed at the control panels. Complete control of the pump system is possible from the control panel at the hydraulic unit. A key-operated master maintenance switch is provided at the control panel in the pump room, which isolates the pump motor circuits for maintenance. An independent maintenance interphone system provides communication between the pump room, computer room, and motion system area.

### 3.2.9.2.12 Installation Requirements

#### 3.2.9.2.12.1 Motion System Room

The MBCS will be installed in Bldg. No. 5 of the Johnson Spacecraft Center at Houston as shown on Figure 2.3.1-1.

The motion system will be installed on the 8 inch thick reinforced concrete floor at the north end of the building. The room is approximately 63 ft. wide x 60 ft. long with a 30 ft. 9" high ceiling extending approximately 32 ft. from the north wall. This space must accommodate the MBCS, the FBCS, the I/O Station and the cabinets desirably located close to the crew station.

The motion system must be positioned to insure clearance of the payload for all possible attitudes of the motion platform. This will require filling of some of the existing cable trenches in the floor and filling some areas now occupied by computer flooring to accommodate installation of the entrance platform.



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### 3.2.9.2.12.2 Hydraulic Power Room Arrangement

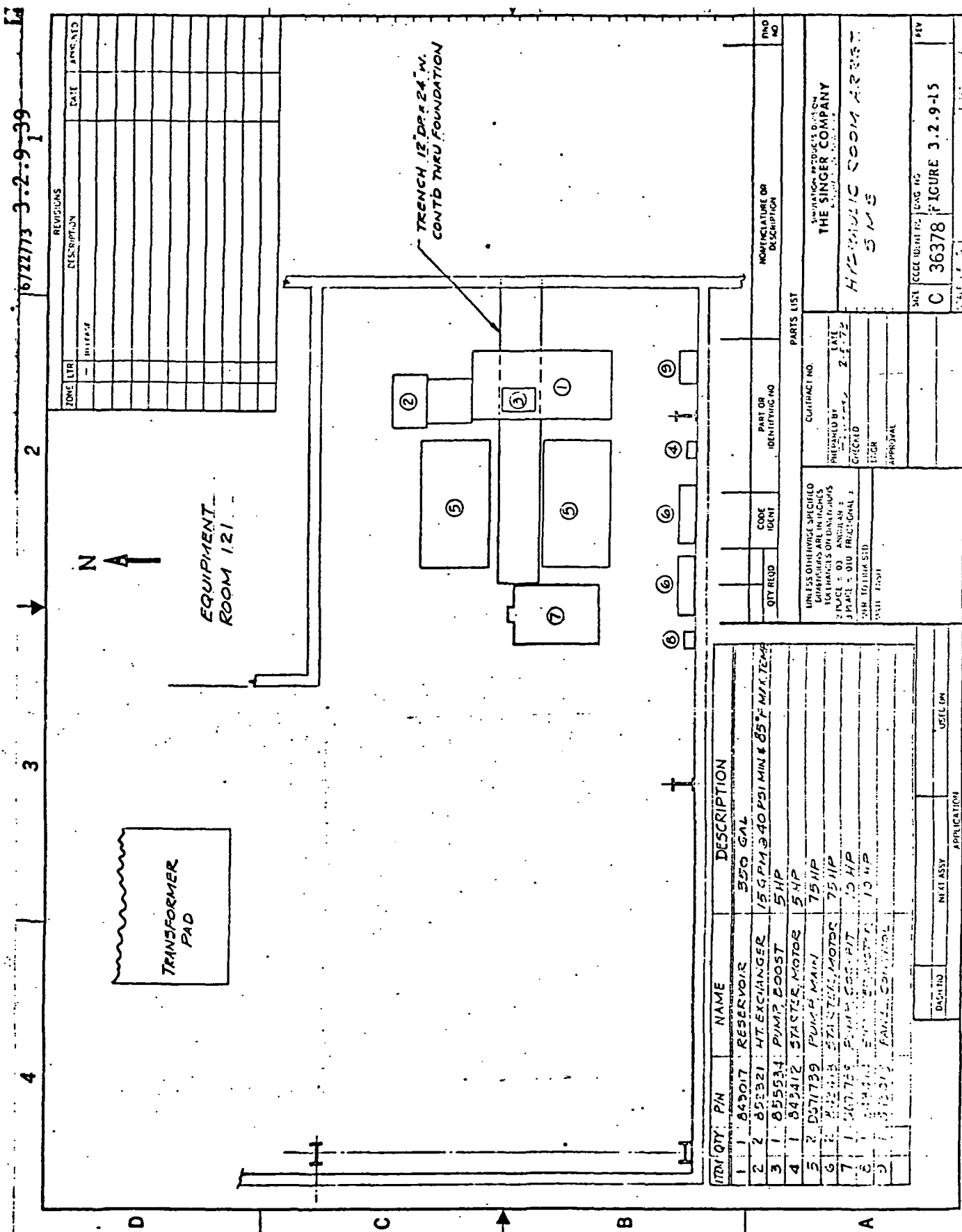
The room at the West end of the building is allocated for the Electrical and Hydraulic Power. This room must accommodate the Hydraulic Power for 3 motion systems, the HFTS and (2) SMS motion based simulators. A proposed arrangement of the required components for this room is shown on Figure 3.2.9-15. A trench must be made in the floor and a hole cut through the wall to accommodate the routing of hydraulic lines to the MBCS, approximately 140 ft. distant.

The following will be provided to accomodate this system.

- 1) 277/480 volt, three-phase, four-wire delta power supply capable of meeting at least the following demands:

| <u>Equipment</u>                | <u>Starting Power (kva)</u> | <u>Running Power (kva)</u> |
|---------------------------------|-----------------------------|----------------------------|
| Main Pump No. 1<br>(75 hp)      | 109                         | 70                         |
| Main Pump No. 2<br>(75 hp)      | 109                         | 70                         |
| Boost Pump (5 hp)               | 34                          | 4                          |
| Control Loading Unit<br>(10 hp) | 64                          | 9                          |
| Air Compression<br>(10 hp)      | 64                          | 9                          |

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2) Water source capable of delivering at least 15 gallons per minute of water at a minimum pressure of 40 psi with a maximum inlet temperature of 85°F.

#### 3.2.9.2.13 Redundant Legs

The motion system will include the redundant leg system. This consists of 6 additional hydraulic actuators placed generally parallel to and inside of the geometry defined by the servoed actuators. They are shown on Figure 3.2.9-16.

They are affixed to the platform and castings on the floor plates in a manner similar to that of the servoed actuators.

These six identical actuators are self-contained hydraulic "springs" exerting a lifting force on the platform as a result of the pressure in a five gallon accumulator attached to each leg. With accumulator pressure set at 200 psi (settled position) these legs exert a heave force of approximately 6300# in settled position and approximately 4290# at maximum high position.

Each piston is designed with tapered fittings which cushion the last 5 inches of stroke in each direction thus decelerating the motion and limiting the shock imposed upon the system and payload.

In addition to this redundant cushioning feature the legs will support the payload in the unlikely event of breakage of a servoed leg or its components.

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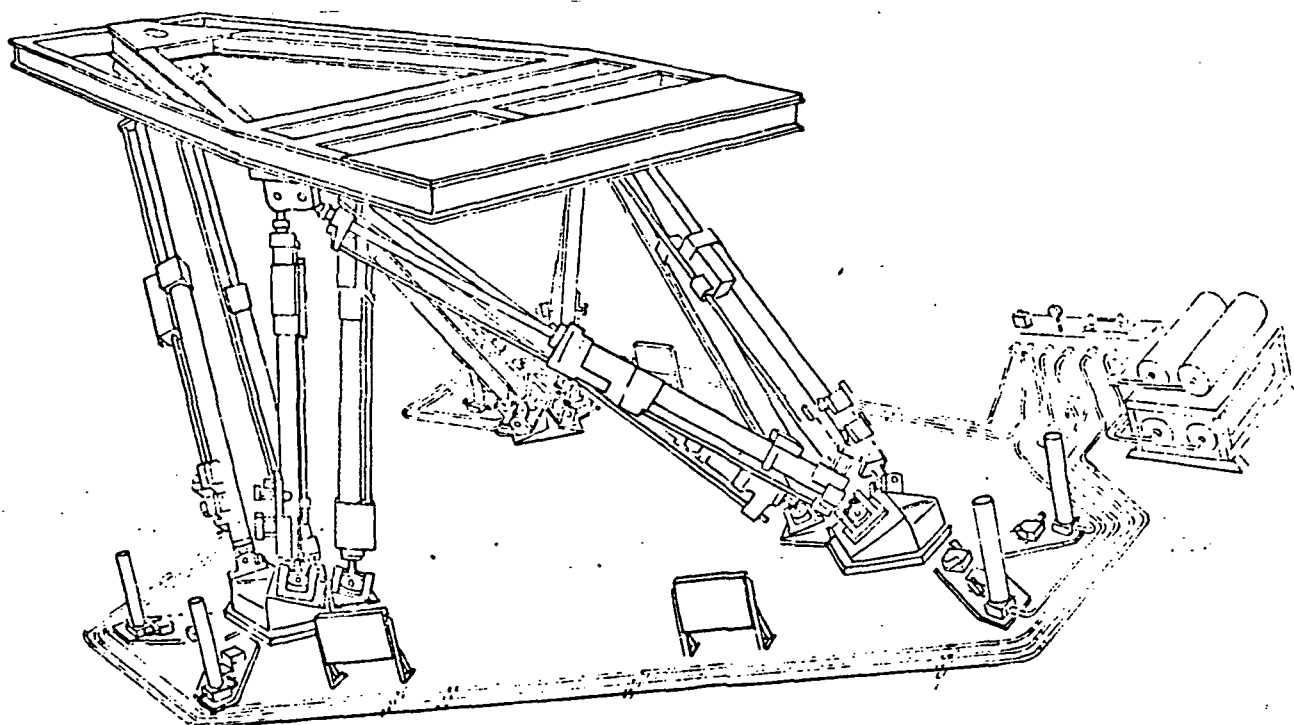


FIGURE 3.2.9-16

SIX-DEGREE-OF-FREEDOM MOTION SYSTEM  
WITH REDUNDANT LEGS

3.2.9.14 Tilt Mechanism

A tilt mechanism is cascaded on the motion platform to provide  $+75^{\circ}$  of positive pitch angle to the crew station, visual system and tilt frame independent of the pitch capability of the motion system. The estimated load to be tilted is approximately 14,400 lbs. (The motion system can add an additional maximum operational pitch of approximately  $34^{\circ}$  for a total positive pitch of  $109^{\circ}$ ).

The tilt mechanism consists of a tilt frame, tilt pivot support frame, drive mechanism, lateral stabilizing mechanism, and the outrigger frames to support the pivots in a lateral axis as shown on Figure 3.2.9-1 and Figure 3.2.9-2.

The tilt frame is a welded platform on which the forward visual system and cockpit can be mounted, and a large arch which surrounds the crew station in a vertical plane providing upper attachment points for the visual system and cockpit. It also contains the structure for the pivot axis.

The tilt frames will be constructed of aluminum alloy structural shapes, sectionalized as necessary to facilitate handling and shipping.

The tilt pivot support frames will be fabricated of welded aluminum tubing, with a split bearing housing bolted at the top, 80" above the platform. The frames will be trussed in both directions and the motion platform will be extended laterally to provide mounting structure for these pivot frames. These outrigger frames will be bolted to the edge of the platform on each side.

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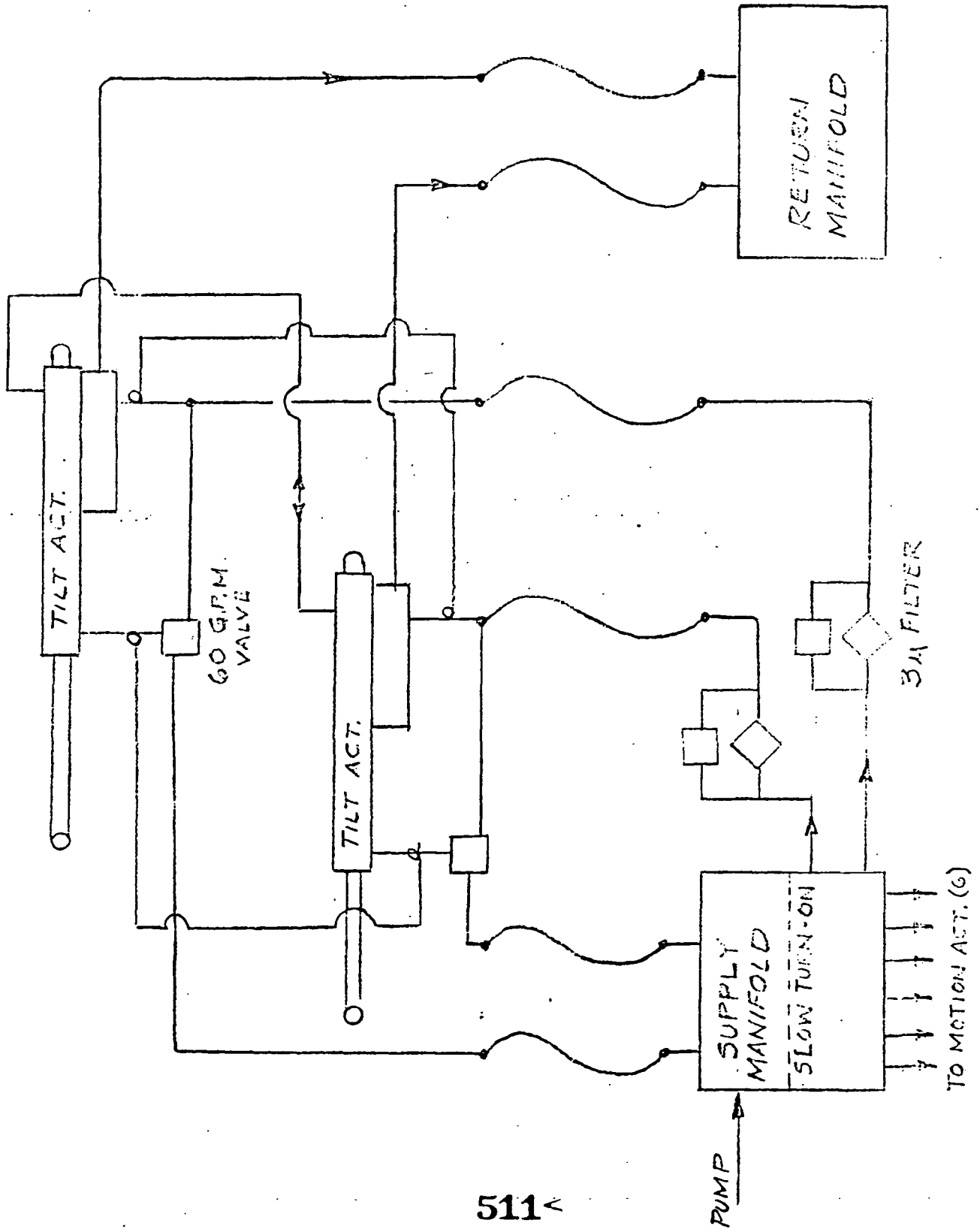


FIG. 3.2.9-17 - HYDRAULIC SCHEMATIC - TILT MECHANISM

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A hydraulic actuator, 3½" bore x 2" rod x 48" stroke with cushioned stroke at each end, will be installed on the outboard side of each pivot frame and attached to a clevis on the tilt frame on each side. These actuators will be servoed to control the attitude and rate of tilt. At both maximum tilt and minimum tilt they will hold the payload steady with full system pressure applied to the actuators.

Each actuator will be supplied thru a 60 G.P.M. servo-valve permitting an average tilt velocity, at rated flow, of 43.5°/second. This velocity can be augmented with the motion system pitch velocity to attain an estimated maximum velocity of 60°/second. However, this velocity must be sustained for a very short duration to permit the "washout" required to minimize the deceleration cues.

Lateral motion will be constrained by a scissors type linkage attached to the underside of the tilt frame and to the motion platform. A redundant lateral restraint will be accomplished with rub plates mounted on the lower edge of the aft tilt frame and aft end of the cockpit which are in contact with mating plates on the pivot frame near the platform surface. These two precautions will limit the side load carried at the tilt pivots and relieve the bending on the pivot frame and the platform extension framework.

The platform extension will be compatible with and bolted to the standard motion platform, extending laterally approximately 30 inches beyond the existing platform profile on each side.

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Hydraulic power for the tilt actuators will be supplied from the existing hydraulic distribution manifold. (Reference Figure 3.2.9-17)

#### 3.2.9.2.15 Entrance Ramp

The aft portion of the flight compartment will be surrounded by a fenced walkway attached to the motion platform. Access to the walkway will be provided by means of a hydraulically powered stairway (see Figure 3.2.9-18) that will automatically rise to the level of the walkway with the platform in the settled position whenever the motion system is deactivated. A separate accumulator will supply power to the stairway actuator in the event of failure of normal hydraulic or electrical power. An interlock will preclude activation of the motion system when the stairway is not fully down in the stowed (horizontal) position. The stairway will be mounted parallel to the rear edge of the motion platform in the settled position, lagged to the concrete subfloor. It will be equipped with tubular safety railing and nonskid (open mesh) stair treads.



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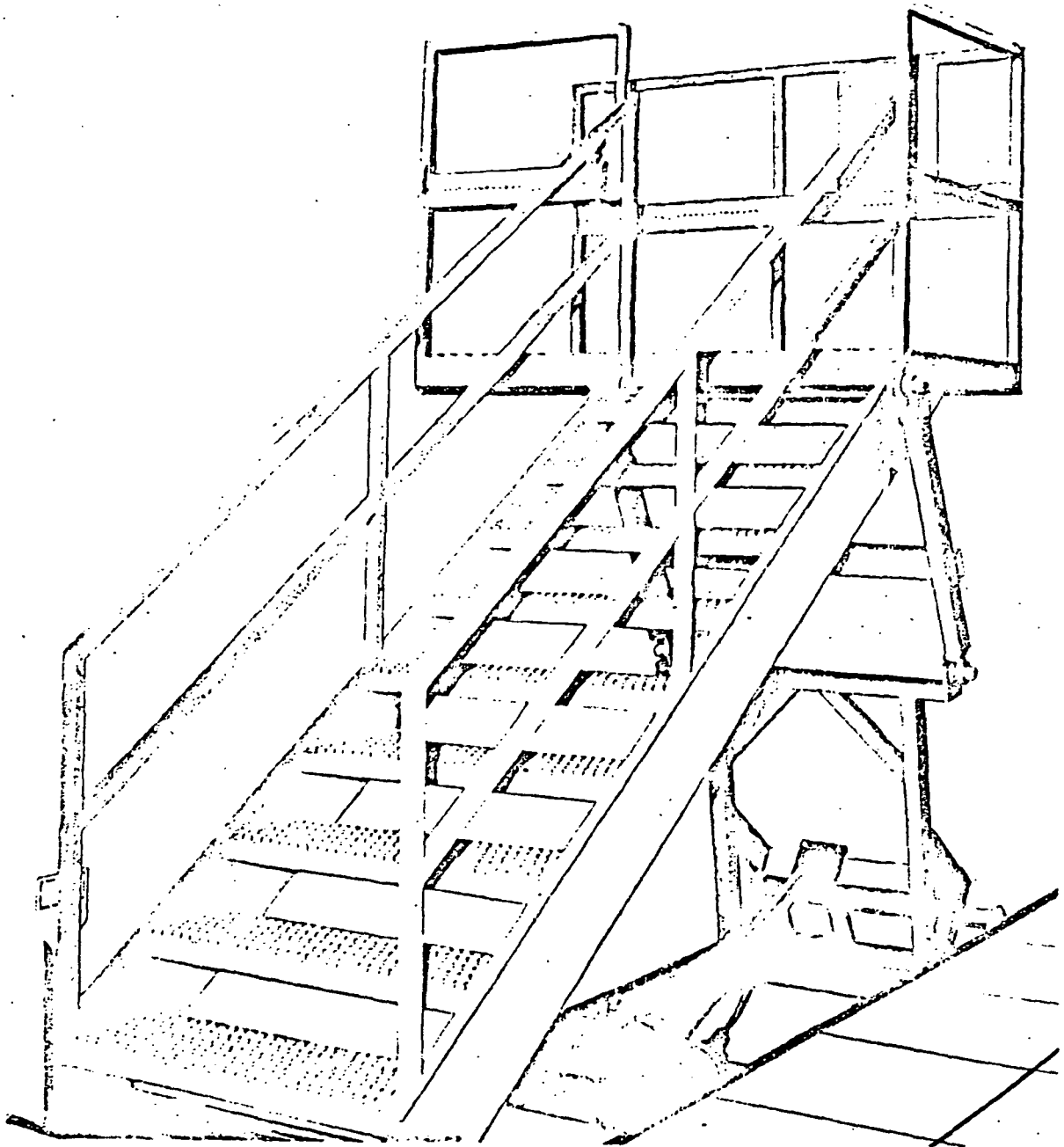


FIGURE 3.2.9-18

MOTION PLATFORM ACCESS STAIRWAY

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### 3.3 Fixed Base Crew Station Equipment

The equipment requirements of the FBCS are defined in Figure 3.3-1.  
The requirements of each major area are as follows:

a) Crew Station - The crew station will be compatible with the forward visual system and aft visual system and provide an active hi-fidelity replica of the entire upper crew station including Commander, Pilot, payload handling, mission specialist and manipulator control work stations.

#### b) Forward Visual System

- (i) Full Field of View Display System
- (ii) Capable of all scene requirements including Launch, Launch Abort, Orbital, Rendezvous, Docking, Station Keeping, Payload Operations, Re-entry, Approach and Landing.

#### c) Aft Visual

- (i) Full Field of View Display System
- (ii) Capable of all scene requirements except Launch, Launch Abort, Re-entry Approach and Landing.

d) On-Board Computer Equipment - This equipment will provide the capability of simulating the vehicle's on-board computers to include

- (i) Data Processing and Software Subsystem System
  - a) DP&S Computers
  - b) Input Output Processors
  - c) Display Electronics Units
  - d) Keyboard and Display Equipment
  - e) Mass Memories

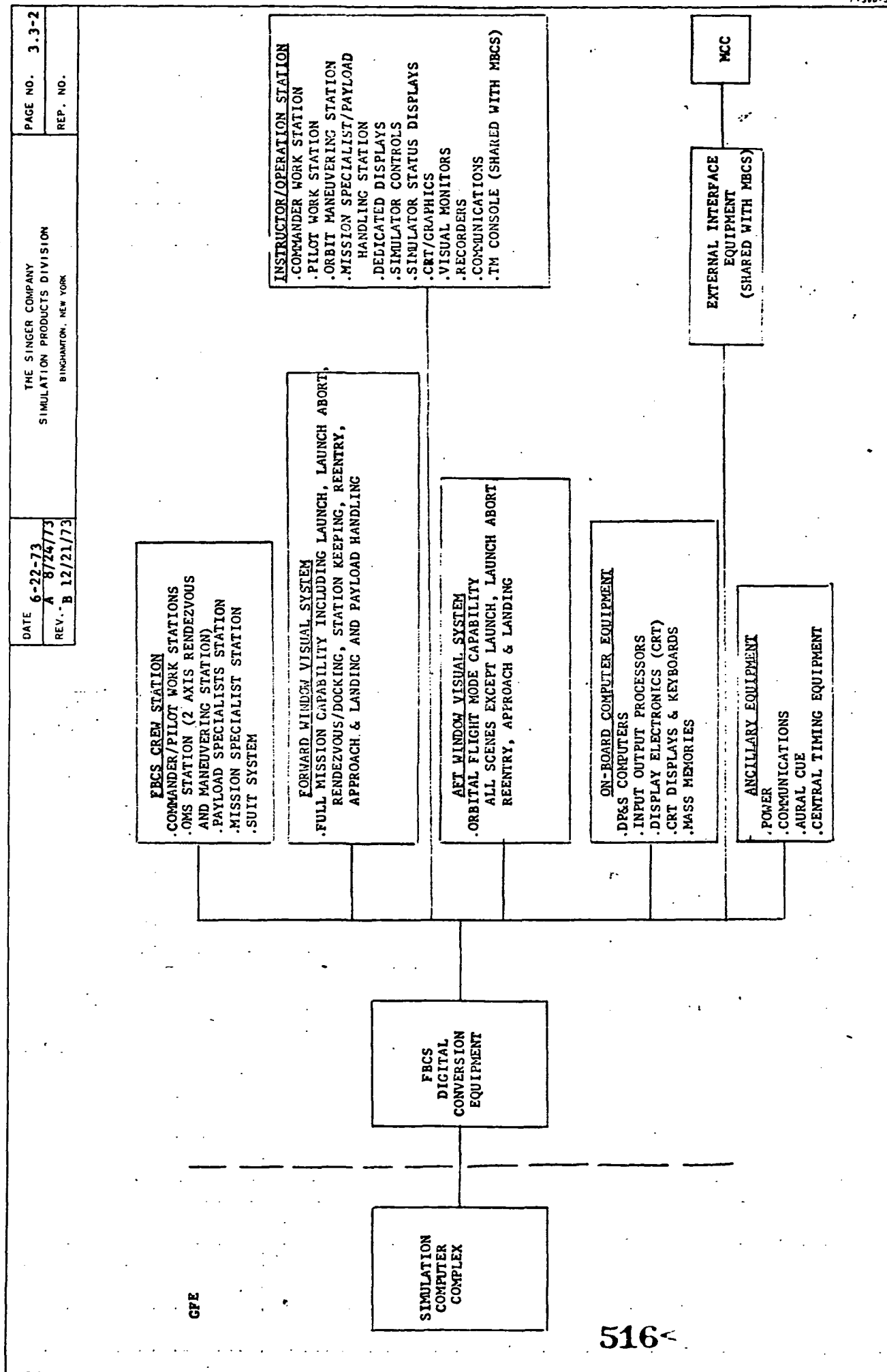


FIGURE 3.3-1 FIXED BASE CREW STATION SIMULATOR EQUIPMENT REQUIREMENTS

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(ii) Main Engine Controller Computers (shared with MECS)

For the purpose of this report, the simulation will be capable of handling the redundancy of computers and the resulting switch-overs for malfunction situations, and for the utilization of flight software.

e) Instructor Operator Station - The instructor operator station for the FECS will be capable of providing the following capabilities:

- (i) Commander Work Station
- (ii) Pilot Work Station
- (iii) Orbit Maneuvering Station (2 Axis Rendezvous & Maneuvering Work Stations)
- (iv) Payload Specialist Station
- (v) Mission Specialist Station
- (vi) Dedicated Monitoring Displays
- (vii) Simulator Status Displays
- (viii) Simulator Controls
- (ix) CRT/Graphic System
- (x) Visual Monitors
- (xi) Data Recording Equipment
- (xii) Communications Equipment
- (xiii) Telemetry Console (shared with MBCS)

The design will be such as to enable three instructors to accomplish training in the non-integrated mode.

f) External Interface Equipment - Equipment which will enable the FBCS to operate in a closed loop mode with MCC will be provided.

g) Ancillary Equipment - Ancillary Equipment requirements fall into a variety of areas namely:

(i) Aural Cue - Equipment will be provided to duplicate the sound heard within the orbiter vehicle during its missions.

(ii) Power - Equipment will be provided to enable building power to be converted to the power types and levels required to operate the MBCS equipment.

(iii) Communications - Equipment will be provided to enable communications between the simulated crew station, IOS, Maintenance areas and MCC.

(iv) Central Timing Equipment - Timing signals will be provided to enable the FBCS, SCC and MCC to operate in a synchronized manner.

h) FBCS Digital Conversion Equipment - The overall SMS DCE design is discussed in Section 3.2.6. Requirements for the FBCS are discussed in Section 3.3.6.

### 3.3.1 FBCS Crew Station

The Fixed Base Crew Station and visual system will be positioned alongside the Motion Based Crew Station, oriented to optimize the space allocated to the SMS in the Houston facility. The arrangement is further described in Section 2.3.1.

The crew station of the fixed base simulator will be a high fidelity replica of the interior of the entire upper floor of the orbiter crew stations. The shell will extend longitudinally from station 450 to station 573, and vertically from W.L. 411 to the top of the module, W.L. 496.

The crew station will be fabricated in two sections for ease of handling and fabrication, joined at station 516. Thus the aft station will be 57" wide x approximately 148" long, x approximately 85" high, plus the protrusion of the removeable overhead observation windows.

The forward section will be essentially identical to that of the motion based simulator except that, when mated with the rear, it will include operable floor hatches which are dummied on the MBCS. The Aft section will be essentially identical to that of the MBCS except that the overhead windows, floor hatch and aft bulkhead will be realistically simulated with aft observation windows and no rear door.

This entire crew station will be mounted on a raised platform such that it will nest within the visual display systems.

The concept is shown in Figure 3.3.1-1.

This raised platform will accommodate 2 ladders and permit ingress and egress and egress thru the floor hatches as accomplished in the spacecraft.

#### 3.3.1.1 Crew Station Structure

The structure for the crew station will be a composite structure of welded aluminum base frame and a shell of molded fiberglass construction, which bolts to the base frame. See Figure 3.3.1-1 and Figure 3.3.1-2.

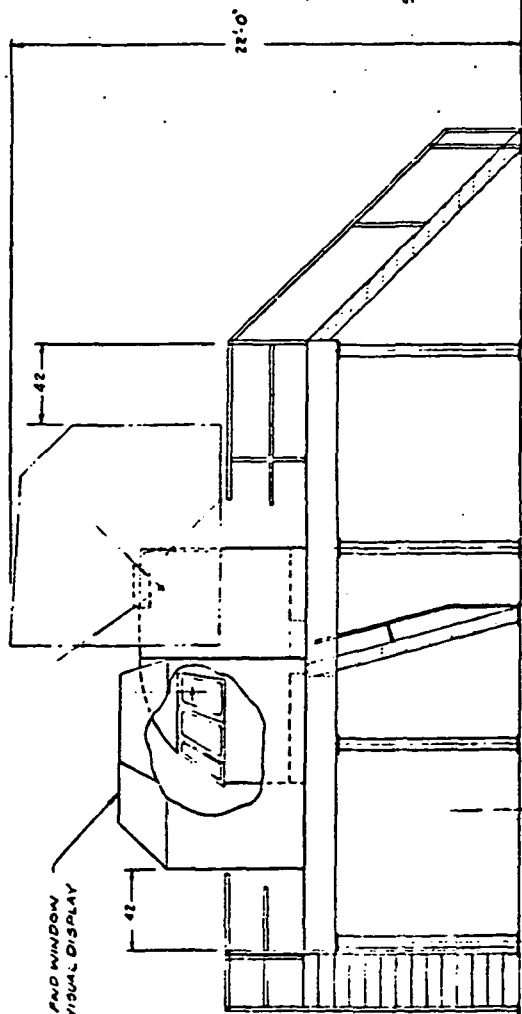
The forward floor frames and shell will be identical to those of the MBCS.

The aft shell and frames will identical to those of the MBCS except as follows:

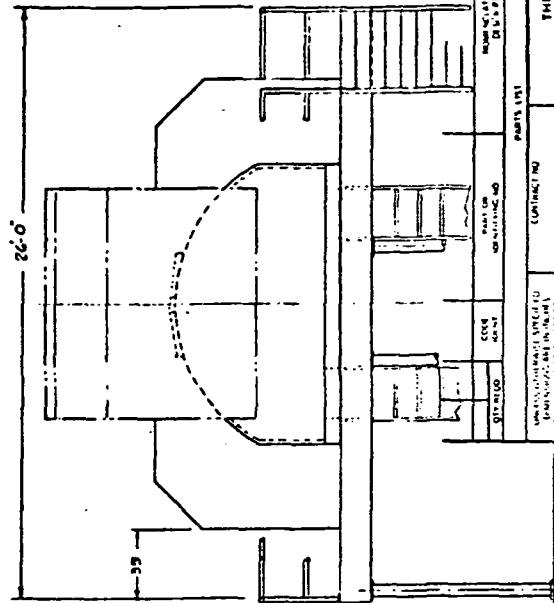
a) The floor frame will incorporate a realistic simulation of the Orbiter entrance hatch, which was dummied on the MBCS.

b) The aft bulkhead will be solid, with the consoles and panels and aft windows fully simulated, in lieu of the compromises made to accommodate the rear entrance door.

c) The overhead window will realistically simulate the orbiter configuration. This will be a bolted on assembly which will protrude approximately 4" above the shell to simulate the visual appearance in this area.



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The seats and seat mounting will be spacecraft items with modifications if necessary to accommodate the repetitive operations typical of simulator use. The consoles, shelves and lining will be installed to duplicate the spacecraft appearance from the interior though the mounting structure will be simplified to reduce weight consistent with maintaining strength incident to the loads imposed by shipping since the fixed base simulator will not be subjected to the accelerations encountered in the flight vehicle.

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#### 3.3.1.2 Control Loading

Control loading for the fixed base simulator will be identical to that of the motion based simulator (Paragraph 3.3.1.2) except for the inclusion of the additional controls at the Remote Manipulator Station. Controls requiring hydraulics will use the hydraulic power of the motion based simulator.

#### 3.3.1.3 Crew Station Air Conditioning

The air conditioning system will be the same as for the motion based simulator, (Paragraph 3.2.1.3), except that the routing of ducts in the aft section will be modified to achieve the high fidelity which was compromised on the motion based simulator. The inlet duct installation also will be simplified since it will not be subject to the excursions of the motion system.

#### 3.3.1.4 Crew Station Control and Display

All crew station controls and displays associated with the shuttle mission will be functional in the FBSCS.

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### 3.3.2 FBCS Instructor Operator Station Complex

The fixed base crew station will provide training associated with both the forward stations and the aft stations. The IOS for this simulator will be equipped to provide instruction for all crew positions, including the OMS station. Integrated training with MCC will be provided from either the MBOS IOS, or the FBCS IOS, but not both simultaneously.

Because of the number of crew positions to be trained on the SMS, the IOS will be designed in modular form. The following modules will comprise the fixed-base IOS: (1) Commander and Pilot, (2) Orbital Maneuvering Station, (3) Mission Specialist, Payload Specialist. The Telemetry Operator Station provided with the MBOS will be shared by both the motion-base and fixed-base crew stations.

In addition to the IOS consoles, the fixed-base IOS complex includes:

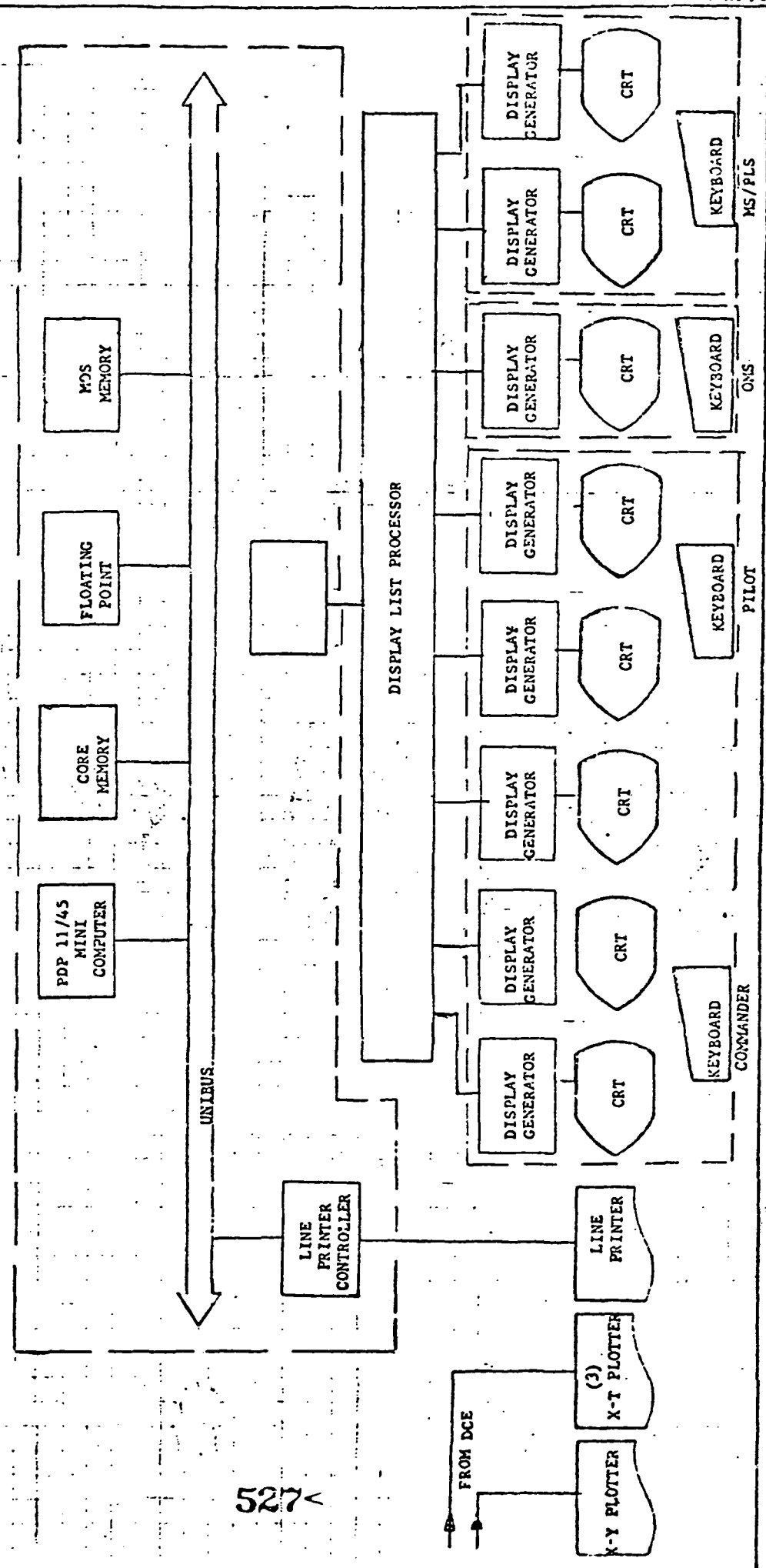
- a. One X-Y recorder
- b. Three eight-channel time history X-T recorders
- c. Four castored, fully adjustable, swivel chairs
- d. One hard-copy print-out device.

The CRT system for the FBCS IOS will also be expanded to include CRT displays and keyboards for the OMS IOS and MS/PLS IOS. Reference Figure 3.3.2-1.

#### 3.3.2.1 Commander-Pilot IOS

The Commander-Pilot IOS for the fixed-base simulator will be identical to the IOS for the motion-base simulator. (Reference

FIGURE 3.3.2-1  
FBGS DISPLAY SYSTEM BLOCK DIAGRAM



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Figure 3.2.2-1). This IOS will include all the features and provide the instructor with the same capabilities offered in the motion-base simulator. Slight modifications will appear on those console panels containing controls for the motion-tilt system and visual system. The motion and tilt controls and status indicators will be eliminated, and additional status indicators will be provided for the visual system related to the docking and manipulator station windows.

For visual system status, an additional bank of indicators will be provided to depict the docking view and manipulator operator windows, termed as follows:

|    |                |
|----|----------------|
| RR | Right Rear     |
| RO | Right Overhead |
| LR | Left Rear      |
| LO | Left Overhead  |

Reference Figure 3.3.2-2 and 3.3.2-3.

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### SIMULATOR STATUS

#### VISUAL

MIP

#### POWER

MIP

ON

#### WINDOWS FORWARD

LS

LQ

LF

RF

RQ

RS

#### DCE

READY

#### AFT

RR

RO

LR

LO

#### COMPUTER

FAULT

READY

#### IMAGE GENERATORS

|  |  |  |  |  |
|--|--|--|--|--|
|  |  |  |  |  |
|--|--|--|--|--|

|  |  |  |  |  |
|--|--|--|--|--|
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FIGURE 3.3.2-2  
FBSC SIMULATOR STATUS PANEL



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### OPERATE CONTROLS

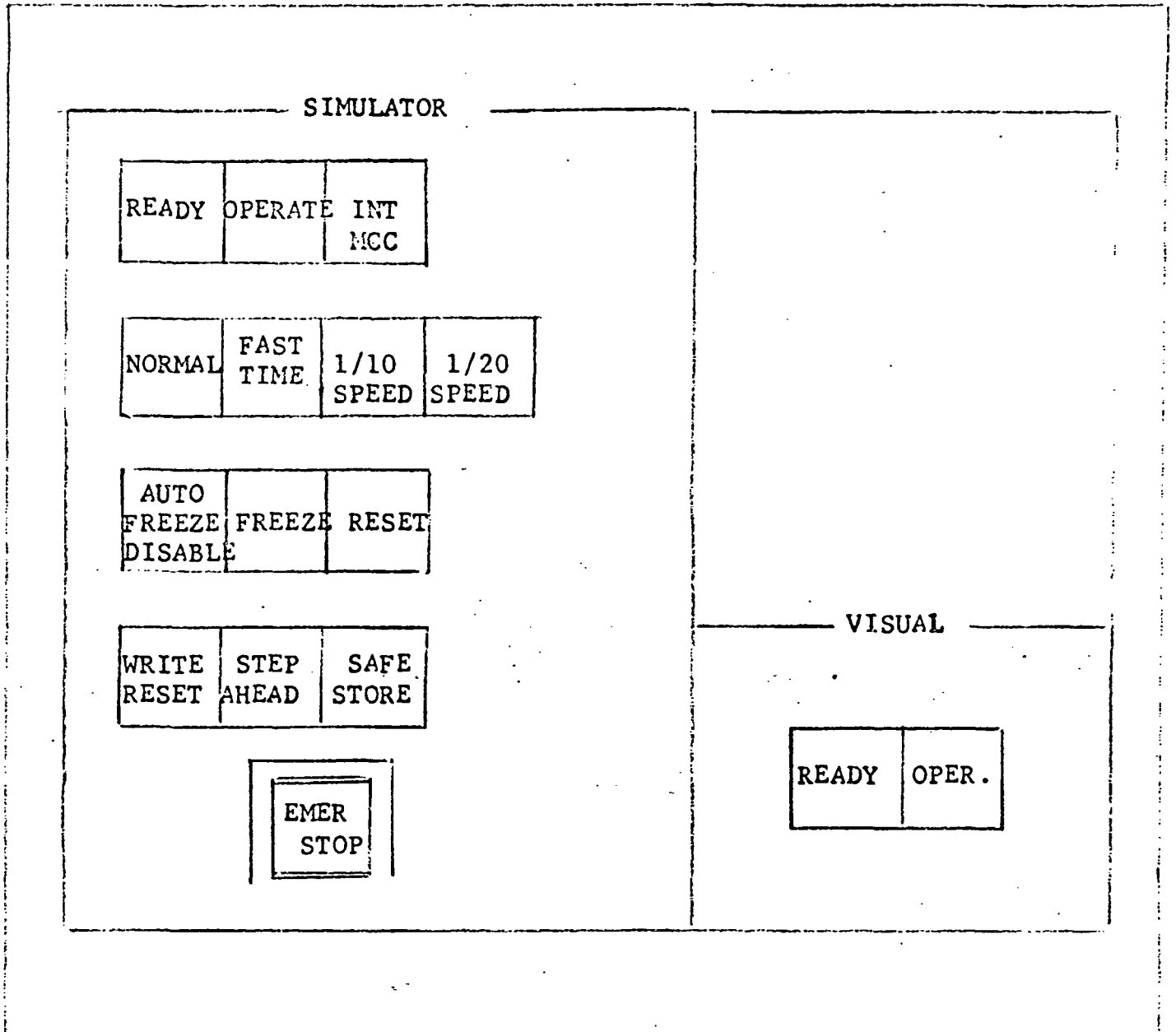


FIGURE 3.3.2-3  
FBCS OPERATE CONTROL PANEL

### 3.3.2.2 Orbital Maneuvering Station IOS

The Orbital Maneuvering Station (OMS) IOS is one of the IOS modules which comprise the fixed-base simulator IOS complex (Reference Figure 3.3.2-4). The station is designed to be manned by one instructor. It is assumed that since the vehicle commander is responsible for the tasks performed at the OMS, the Commander instructor will also serve as the instructor at this IOS. Based on this premise, the OMS IOS will be located adjacent to the Commander's IOS. The OMS will provide control and monitoring capability for both the Z Axis Rendezvous and the maneuvering work stations.

The OMS IOS will be vertically stacked similar to the Commander-Pilot IOS. The upper segment will be canted downward at a 30 degree angle from the vertical. The center segment will be vertical, and the lower segment will be inclined 45 degrees from the horizontal, and joins the horizontal writing surface. With this design, the instructor's line-of-sight will be approximately perpendicular to the center of each tier.

The writing surface will be 16 inches deep to provide adequate space for reference materials and for writing. The height of the writing shelf above the floor is  $25\frac{1}{2}$  inches (in conformity with MIL-STD-1472 and MSFC-STD-267A) which allows the keyboard unit to be at a comfortable level, and yet provides ample knee room for the instructor.

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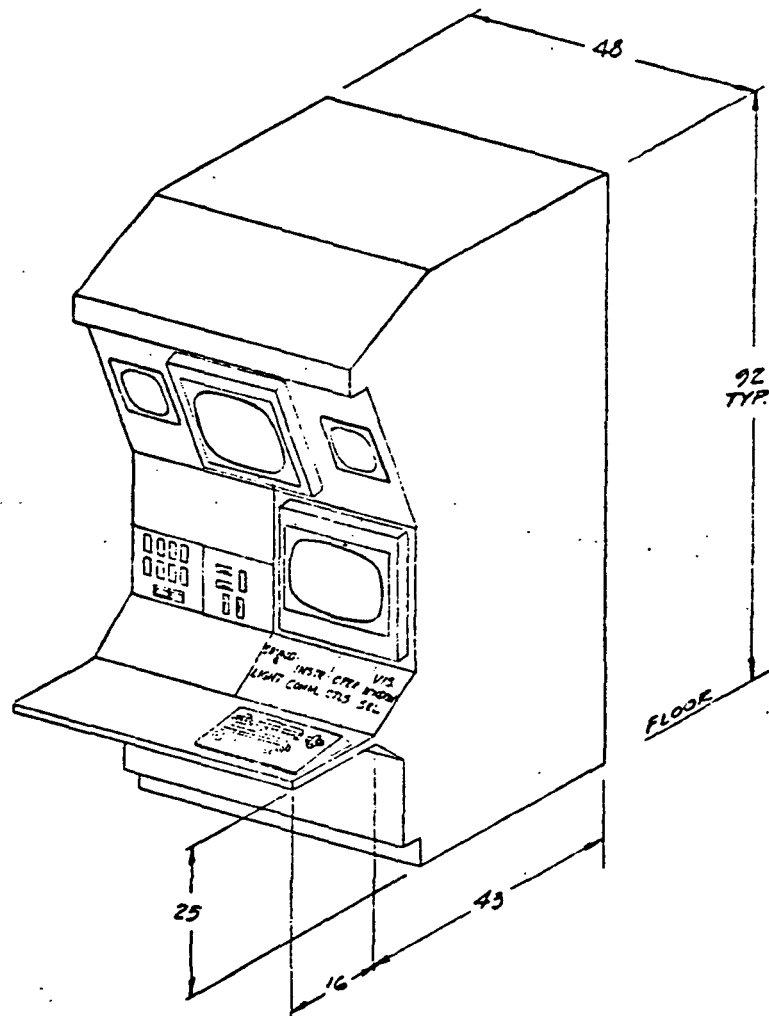
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OMS CONSOLE  
FOR FBCS SIMULATOR

FIGURE 3.3.2-4

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The upper tier of the IOS will consist of a visual monitor and two TV monitors which are repeaters of those located at the OMS in the crew station. The visual monitor will permit the instructor to monitor the visual scenes portrayed on the docking and manipulator station windows. The center tier will consist of an alphanumeric CRT and dedicated instruments. Additional space is provided on this panel for future growth. The lower tier will house the controls required for operation of this station. A keyboard unit will be located at the OMS IOS which would operate in conjunction with the CRT unit.

3.3.2.2.1 CRT Display/Keyboard Units

The keyboard/display unit will operate identically to those described previously in Section 3.2.2.1.1, and the same keyboard action will be used to select a display or modify a value stored in the computer. The top line of the CRT will always contain the following data:

- a. A one-or two-character display mnemonic identifying the display.
- b. Symbols indicating the ground station in contact with the vehicle; if none are in contact, LOS is displayed.
- c. Mission elapsed time
- d. Simulated Greenwich mean time

CRT pages, identical to those available at the Commander-Pilot IOS, will be provided at the OMS IOS.

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A description of these displays and the method by which the displays are called up is as outlined in 3.2.2.1.1 and 3.2.2.1.2.

At the OMS IOS, a separate CRT is not dedicated to the Event Time Monitoring page. This page will provide a chronological listing of the most recent crew actions. The most recent crew action will be displayed on the top line of the CRT. As the next action takes place it will occupy the first line and the previous action will be moved to the second line. When the CRT page is filled, a new action will cause the last line on the page to be dropped from the display. Each line will contain the following data:

- a. The name of the control manipulated
- b. The action taken: For a non-momentary switch, the new position will be displayed. For a momentary switch or a continuous control, the direction of the most recent motion would be shown.
- c. The time at which the switch action occurred.
- d. The mnemonic of the system page involved.

To call up the Event Time Monitor page, the instructor will use the same procedure specified in section 3.2.2.1.1.3.

#### 3.3.2.2.2 Dedicated Instruments

The following instruments located at the OMS will be repeated at the IOS to permit the instructor to monitor the trainee's performance (Reference Figures 3.3.2-5 and 3.3.2-6).

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- a. Roll Rate & Error Indicator
- b. Pitch Rate & Error Indicator
- c. Yaw Rate & Error Indicator
- d. RR Elevation Indicator
- e. RR Range Indicator
- f. RR Azimuth Indicator
- g. Monitor 1 (TV)
- h. Monitor 2 (TV)

#### 3.3.2.2.3 Simulator Control and Display

The IOS control panel will contain the necessary controls and indicators for operation of the IOS. Sufficient controls will be provided to operate the station individually as a part task trainer or in concert with the other IOS's for integrated crew training. The following control panels will be provided at the IOS:

- a. Operate Controls
- b. Communications Controls
- c. Visual Window Select Controls (Reference Figure 3.3.2-7).
- d. Sound/Lighting Controls

#### 3.3.2.2.3.1 Operate Control Panel

The Operate Control Panel will contain all the necessary controls and indicators to operate the OMS of the simulator. The controls contained on this panel will be identical to those controls contained on the same panel at the Commander-Pilot IOS for the fixed-

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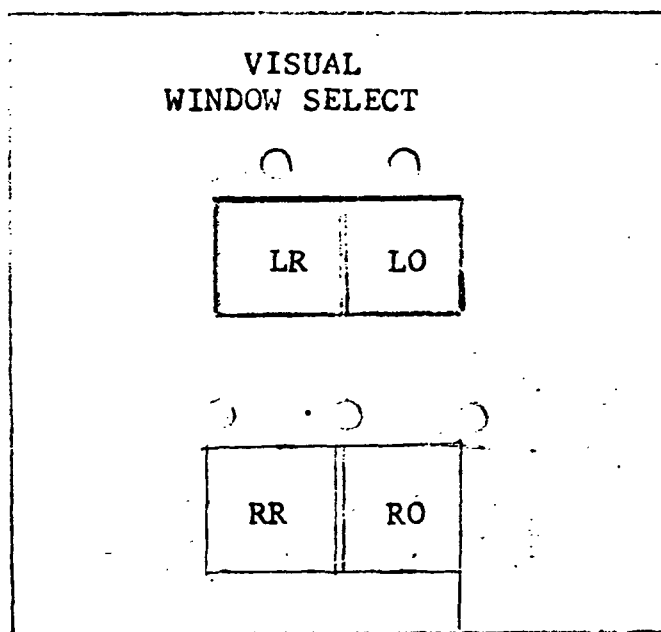
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VISUAL WINDOW SELECT PANEL

FIGURE 3.3.2-7

|                              |  |                   |
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base simulator. A functional description of the controls is the same as discussed in Section 3.2.2.1.3.2.

### 3.3.2.2.3.2 Communications Control Panel

This panel will contain all the necessary controls for instructor to communicate with the trainee, other instructors, and personnel in support of the training exercise. The controls on this panel will be the same as those on the Commander-Pilot IOS console for the fixed-base simulator and are described in 3.2.2.1.3.4.

### 3.3.2.2.3.3 Visual Window Select Panel

This panel will provide the instructor with the necessary controls to select a scene being portrayed in one of the Z Axis Rendezvous or Manipulator station windows. Selection of the window to be displayed on the Visual Monitor will be made through a switch-light. Tell-tale lights located above the switch-light will indicate the window at which a visual scene is being portrayed. The following switch-lights, when activated will call up the appropriate window scene on the visual monitor.

|    |                |
|----|----------------|
| LR | Left Rear      |
| LO | Left Overhead  |
| RR | Right Rear     |
| RO | Right Overhead |

### 3.3.2.2.3.4 Sound/Lighting Control Panel

This panel will contain the same controls and indicators presented on the Commander-Pilot IOS. Their function is described in Section 3.2.2.1.3.5.

### 3.3.2.2.3.5 Hand Controller Indicator Panel

A hand controller indicator panel similar to that described in paragraph 3.2.2.1.3.2 will be provided to monitor the rotation and translation hand controllers.

### 3.3.2.3 Mission Specialist/Payload Specialist IOS

The Mission Specialist/Payload Specialist (MS/PS) IOS is designed to be manned by one instructor. The instructor will be provided with all the controls necessary to operate the simulator in a non-integrated mode or for mission rehearsals integrated with MCC. The instructor console will integrate two CRT display units, a keyboard unit, TV monitors, dedicated displays, a control panel used for functions not accomplished with the keyboard unit, and an audio panel to provide the necessary communications functions.

The MS/PS IOS will be vertically stacked similar to the Commander-Pilot IOS (Reference Figure 3.3.2-8). The upper segment is canted downward at a 30 degree angle from the vertical. The center segment is vertical, and the lower segment is inclined 45 degrees from the horizontal, and joins the horizontal writing surface. With this design, the instructor's line-of-sight will be approximately perpendicular to the center of each tier.

The writing surface will be 16 inches deep to provide adequate space for reference materials and for writing. The height of the writing shelf above the floor will be 25½ inches which allows the keyboard unit to be at a comfortable level and yet provides ample knee room for the instructor.

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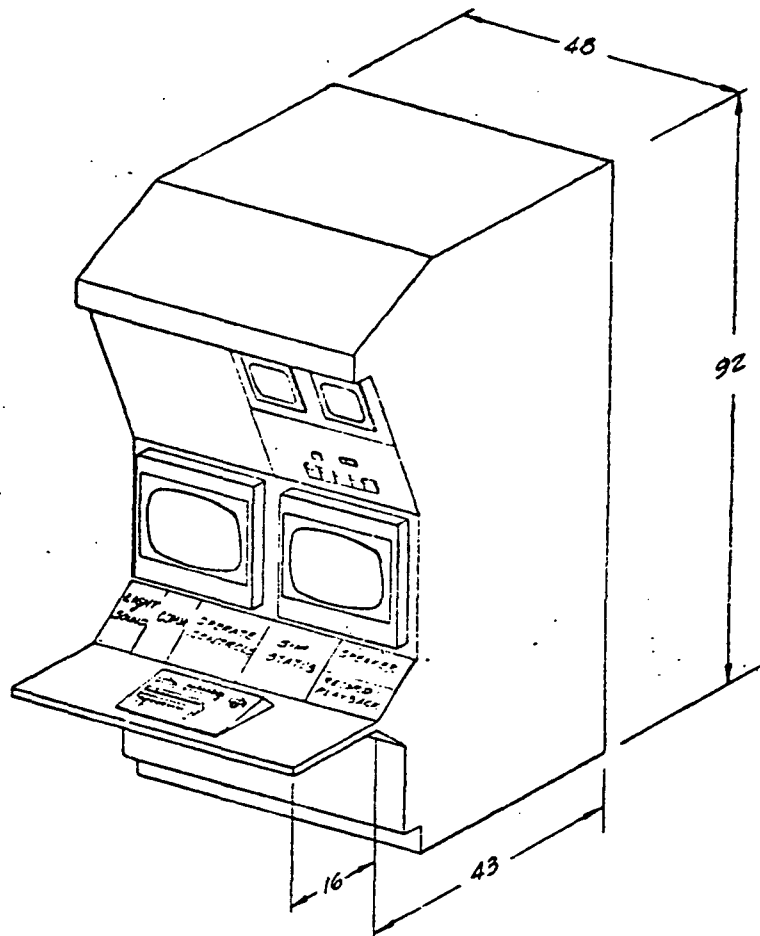
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MS/PS CONSOLE  
FOR FBCS SIMULATOR

FIGURE 3.3.2-8

|                 |  |                  |
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The upper tier of the IOS consists of two TV monitors which are repeaters of those located at the Mission Specialist Station. This tier also provides space for dedicated instruments. The center tier contains two alphanumeric CRT's, and the lower tier includes those controls required for operation of this station. At the time of this report, no diagrams were available which describe the configuration of the Payload Specialist's panel within the SSV. However, space is provided at the IOS for TV monitors and dedicated instruments which may be required for this crew position.

#### 3.3.2.3.1 CRT Display/Keyboard Units

The MS/PS IOS will provide the instructor with the two CRT display units. Either CRT will have the capability of displaying alphanumeric or graphic data depending upon the page which is called up. The keyboard unit, centrally located on the writing surface between the two CRT's will operate identically to those located at the Commander/Pilot IOS and described above in 3.2.2.1.1, and the same keyboard action will be used to select a display or modify a value stored in the computer.

CRT display pages identical to those available at the Commander/Pilot IOS will be available at the MS/PS IOS.

A description of these displays and the method in which the displays are called up on the CRT is the same as outlined in sections 3.2.2.1.1 and 3.2.2.1.2.

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At the MS/PS IOS a separate CRT is not dedicated to the Event Time Monitoring page as is the case at the Commander/Pilot IOS. This page and its contents are as described in 3.2.2.1.1.1.

### 3.3.2.3.2 Dedicated Instruments

The following instruments located at the Mission Specialist station of the crew cabin will be repeated at the MS/PS IOS. This listing does not include dedicated instruments for the Payload Specialist station which are TBD.

- a. Caution and Warning Indicators
- b. Master Alarm Indicator
- c. Event Time Meter
- d. CRT-1 Monitor
- e. CRT-2 Monitor



### 3.3.2.3.3 Simulator Control and Display

The MS/PS IOS will contain the necessary controls and indicators for operation of the IOS in conjunction with the other IOS's for non-integrated crew training or for mission rehearsals integrated with MCC. The following control panels are provided at the MS/PS IOS.

- a. Simulator Status
- b. Operate Controls
- c. Communications Controls
- d. Lighting/Sound Controls
- e. Record/Playback Controls
- f. Speaker Controls

#### 3.3.2.3.3.1 Simulator Status Panel

The Simulator Status Panel provides a visual indication to the instructor of the status of the simulator and its associated sub-systems. The panel is located in a central location of the IOS console to facilitate convenient access and ease of viewing by the instructor. The following is a description of the controls located on this panel.

##### Power System Status

"MIP" - This indicator, when illuminated, represents that maintenance is in progress.

"ON!" - When all power required from the main power source is available to the simulator for its operation, this indicator will illuminate.

#### DCE Status

"READY" - Illumination of this indicator denotes that the DCE unit is tied into the simulator and "READY" for operation.

#### Computer Status

"FAULT" - The computer fault light will indicate when a fault has been detected. When the source of the fault is removed, the light will be extinguished. If the fault is transient, the light will not stay on. The computer fault indicator is only active when the computer is off-line and not operating in a mission mode.

"READY" - This indicator, when illuminated, signifies that the computer is tied into the simulator and the simulator is "READY" for operation.

#### 3.3.2.3.3.2 Operate Control Panel

The Operate Control Panel contains the necessary controls and indicators to operate the Mission and Payload Specialist station of the simulator. The controls contained on this panel are identical to those controls contained on the same panel at the Commander-Pilot IOS for the fixed-base simulator. A functional description of the controls is the same as discussed in Section 3.2.2.1.3.2.

|                 |  |                  |
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#### 3.3.2.3.3.3 Communications Control Panel

This panel contains all the necessary controls for the instructor to communicate with the trainee, other instructors, and personnel in support of the training exercise. The controls on this panel are the same as those on the Commander-Pilot IOS for the fixed-base simulator and are discussed in Section 3.2.2.1.3.4.

#### 3.3.2.3.3.4 Lighting/Sound Control Panel

This panel contains the same controls and indicators presented on the Commander-Pilot IOS. Their function is described in Section 3.2.2.2.1.3.5.

#### 3.3.2.3.3.5 Record/Playback Control Panel

These controls, in conjunction with the keyboard unit are used to record the trainee's performance and play it back at a subsequent time. The controls on this panel are the same as those located at the Commander-Pilot IOS for the fixed-base simulator. The function of the controls are described in Section 3.2.2.1.4.3.

3.3.2.3.3.6 Speaker Control Panel

A speaker is provided at the MS/PS IOS to monitor the communications conducted at the crew positions in the simulator (Reference Figure 3.3.2-9). The speaker is supplied in addition to the instructor's headset. The controls and their function are:

"VOLUME" - This control permits the sound intensity of the speaker to be varied.

"SPKR ON" - Activation of this dual-action switch-light permits communications to be heard over the speaker system.

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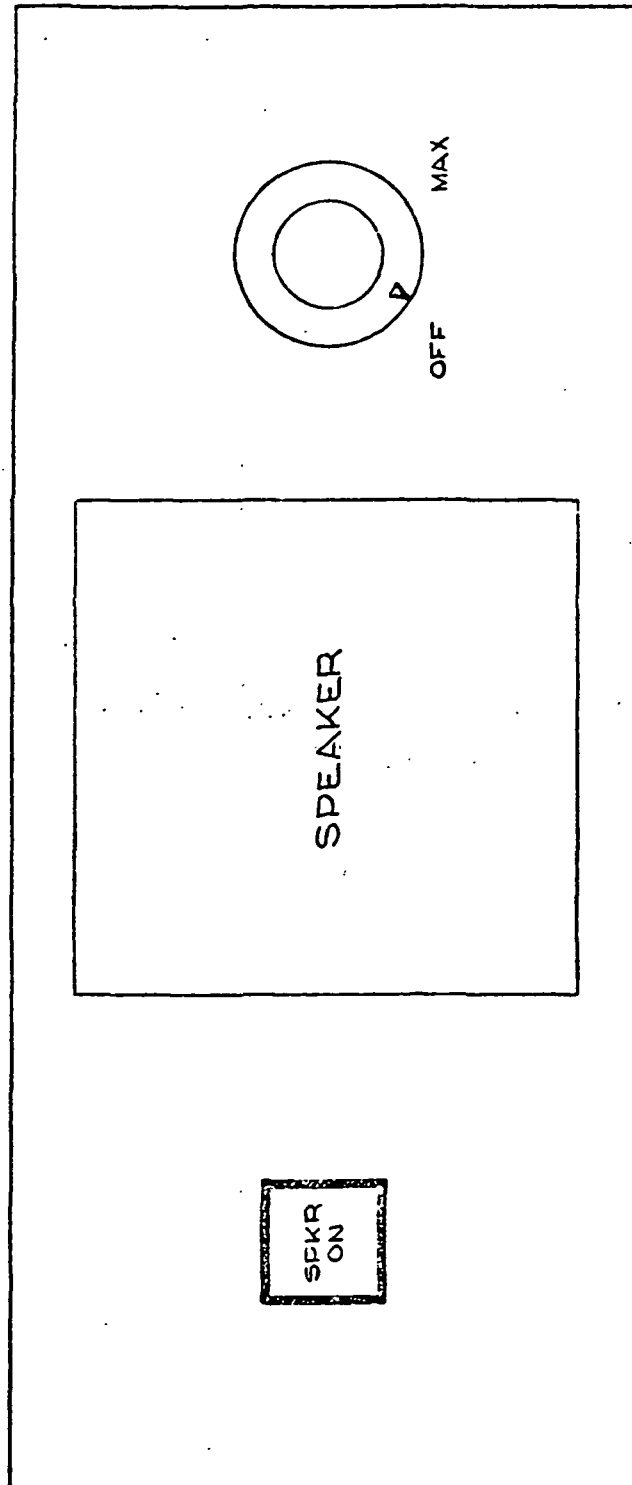
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SPEAKER PANEL, MS/PS IOS

FIGURE 3.3.2-9

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3.3.2.4 Layout Mock-Up

A layout of the instructor area along with the justification for that layout will be provided at the contractor's plant prior to establishing firm requirements relative to the overall layout. Where major components are duplicated on the console (e.g., CRT displays) only one will be modeled in detail. The model will be as complete as necessary to permit evaluation of the general arrangement and installation of the following equipment.

- a. Location of the IOS's with respect to crew compartment stations
- b. Instructor-operator flight compartment controls
- c. Full scale replica of all cabinets and panels including controls and indicators located in the instructor-operator areas
- d. Instructor chairs
- e. Lighting arrangement
- f. Sample of panel painting and engraving

### 3.3.3 FBCS Ancillary Equipment

#### 3.3.3.1 Simulator Power Hardware

The SMS complex will have only one main AC power control cabinet. It will be shared by the FBCS and MBCS simulators. The FBCS and MBCS will have separate, but identical DC Power Cabinets. Refer to Section 3.2.3.1.

#### 3.3.3.2 Aural Cue

The aural cue equipment provided for the FBCS will be identical to that provided in the MBCS. Refer to Section 3.2.3.2 for a description of this equipment.

#### 3.3.3.3 External Interface Equipment

The External Interface Equipment provided with the MBCS will be shared by the FBCS. Refer to Section 3.2.3.3 for descriptions of this equipment.

#### 3.3.3.4 Central Timing Equipment

The Central Timing Equipment provided with the MBCS will be shared by the FBCS. Refer to Section 3.2.3.4 for a description of this equipment.

#### 3.3.3.5 Audio Communications System

Additional Audio Communications Equipment will be provided for the FBCS and its associated IOS including an audio station for the OMS in the crew station, and for the MS/PLS and OMS IOS. Refer to Section 3.2.3.5 for descriptions of this equipment.

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### 3.3.4 FBCS On-Board Computers

The Fixed Base Crew Station OBC simulation will incorporate an additional five DP&S computers; one for Guidance, Navigation, Flight Control, Performance Monitoring and Payload Handling.

The simulation of the Main Engine computers provided in the MBCS will be shared by the FBCS. The additional (GFE) CRT Displays and Keyboards for all crew positions will be provided, with repeater CRT's for the IOS. Two additional Mass Memory Units will also be provided for the FBCS. Figure 3.2.4-3 is a block diagram of the system. One additional minicomputer will be included in the FBCS to provide the interface between the SCC and the CIC/DP&S on-board computers and to provide the processing, formatting and control for the OBC CRT system and Mass Memories.

Tables 3.3.4-1 and 3.3.4-2 summarize the I/O requirements of the MCM and CIC/DP&S.

Table 3.3.4-3 is a computer loading estimate for the computer which indicate the resident program software requirements.



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| <u>DATA TYPE</u> | <u>QTY.</u> | <u>HALF-<br/>WORDS</u> | <u>INPUT RATE</u> | <u>HALFWORDS<br/>TOTAL SEC</u> |
|------------------|-------------|------------------------|-------------------|--------------------------------|
| SENSOR DATA      | 210         | 420                    | 25                | 10500                          |
| MANUAL CTLS      | 67A         | 134                    | 25                | 3350                           |
|                  | 39D         | 39                     | 25                | 975                            |
| FLT CTLS         | 191         | 382                    | 25                | 9550                           |
| UPLINK           | 20          | 20                     | 1                 | 20                             |
| INTERCOMPUTER    |             |                        |                   |                                |
| (PM)             | 256         | 512                    | 5                 | 2560                           |
| MASS MEMORY      |             |                        |                   |                                |
| PAYLOAD MONITOR  | *240        | 480                    | 10                | 4800                           |
| DACBU            | 140         | 280                    | 5                 | 1400                           |
| (DISCRETES)      | 80          | 80                     | 5                 | 400                            |
| GMT              | 3           | 3                      | 25                | 75                             |
| CONTROL          | 20          | 20                     | 25                | 500                            |
| TOTALS           |             | 998                    | 20                | 24950                          |
|                  |             | 480                    | 10                | 4800                           |
|                  |             | 872                    | 5                 | 4360                           |
|                  |             | 20                     | 1                 | 20                             |
|                  |             | <hr/>                  |                   | <hr/>                          |
|                  |             | 2370                   |                   | 34130                          |

\* = ESTIMATED 10% OF 2400 BUFFERED QUANTITIES CHANGE/SEC

TABLE 3.3.4-1A  
FBCS ESTIMATED WORSE CASE INPUT  
HOST TO MINICOMPUTER  
DATA RATES

| <u>DATA TYPE</u>              | <u>QTY.</u> | <u>HALF-WORDS</u> | <u>INPUT RATE</u> | <u>HALFWORDS<br/>TOTAL/SEC</u> |
|-------------------------------|-------------|-------------------|-------------------|--------------------------------|
| SENSOR COMMANDS               | 76          | 152               | 25                | 3800                           |
| FLT COMMANDS                  | 118         | 236               | 25                | 5900                           |
| CREW INTERFACE                | 50          | 40                | 5                 | 200                            |
| MANIP ARMS                    | 15          | 30                | 25                | 750                            |
| INTERCOMPUTER                 |             |                   |                   |                                |
| GN&C TO AUX COMP              |             |                   |                   |                                |
| MISC (TELE, ANT<br>SEL, ETC.) | 10          | 10                | 1                 | 10                             |
| SIGNAL PROC<br>(DACBU)        | 700         | 1400              | 1                 | 1400                           |
| DISCRETES                     | 80          | 80                | 5                 | 400                            |
| PAYLOAD MONITOR               | *240        | 480               | 10                | 4800                           |
| PM ANNUC                      | 10          | 10                | 10                | 100                            |
| INPUT SENSOR DATA             | 210         | 420               | 25                | 10500                          |
| MAN CTLS                      | 67A         | 134               | 25                | 3350                           |
|                               | 39D         | 39                | 25                | 975                            |
| FLT CTLS                      | 191         | 382               | 25                | 9550                           |
| UPLINK                        | 20          | 20                | 1                 | 20                             |
| MASS MEMORY                   | -           | -                 |                   |                                |
| GMT                           |             |                   |                   |                                |
| TOTALS                        |             | 1393              | 20                | 34825                          |
|                               |             | 490               | 10                | 4900                           |
|                               |             | 120               | 5                 | 600                            |
|                               |             | <u>1430</u>       | 1                 | <u>1430</u>                    |
|                               |             | 3433              |                   | 41755                          |

\*ESTIMATE 10% of  
2400 QUANTITIES CHANGE

TABLE 3.3.4-1B  
FBCE ESTIMATED WORSE CASE OUTPUT  
MINICOMPUTER TO HOST DATA RATES

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MINI TO FBCS DP&S

|                   | <u>HALFWORDS</u> | <u>RATE</u> | <u>HALFWORDS/SECOND</u> |
|-------------------|------------------|-------------|-------------------------|
|                   | 607              | 25          | 15175                   |
|                   | 240              | 10          | 2400                    |
|                   | 276              | 5           | 1380                    |
|                   | <u>30</u>        | 1           | <u>30</u>               |
| TOTAL             | 1153             |             | 18985                   |
| TOTAL X 5 =       | 5766             |             | 94925                   |
| AVERAGE PER CYCLE | 760              |             |                         |
| AVERAGE X 5       | 3800             |             |                         |

FBCS DP&S TO MINI

|                   |            |    |            |
|-------------------|------------|----|------------|
|                   | 234        | 25 | 5850       |
|                   | 10         | 10 | 100        |
|                   | 80         | 5  | 400        |
|                   | 400        | 2  | 800        |
|                   | <u>700</u> | 1  | <u>700</u> |
| TOTAL             | 1424       |    | 7850       |
| TOTAL X 5 =       | 7120       |    | 39250      |
| AVERAGE PER CYCLE | 315        |    |            |
|                   | 1575       |    |            |

TABLE 3.3.4-2  
FBCS MASTER CONTROLLER/CIC/DP&S  
DATA TRANSFERS

| PROGRAM ELEMENT          | INSTRUCTIONS | DATA | TOTAL<br>MEMORY | RATE      | LOOPING | TOTAL<br>LOOPS | MICRO<br>SECONDS<br>PER<br>LOOP | MICROSECONDS<br>PER<br>SECOND |
|--------------------------|--------------|------|-----------------|-----------|---------|----------------|---------------------------------|-------------------------------|
| EXECUTIVE/MONITOR        | 6000         | 1000 | 7000            | 25        | 1       | 25             | 1000                            | 25,000                        |
| MASTER CONTROL TIMING    | 1000         | 200  | 1200            | 25        | 1       | 25             | 500                             | 12,500                        |
| IOB NO. 1,2,3,4,5 (BITE) | 1000         | -    | 1000            | 25        | 5       | 125            | 1500                            | 187,500                       |
| AVIONICS SUBSYSTEM H/M   | S.R.         | 2208 |                 |           |         | 13740          |                                 | 137400                        |
| ANALOG DATA M/H          | S.R.         | 159  | 5500            | 20,10,5,1 | -       | 16740          | 10                              | 167400                        |
| AVIONICS SUBSYSTEM H/M   | S.R.         | 162  |                 |           |         | 1660           |                                 | 33200                         |
| DISCRETE DATA M/H        | S.R.         | 159  | 300             | 20,10,5,1 | -       | 1320           | 20                              | 26400                         |
| (5) DEU/CRT DRIVES       | S.R.         | 2000 | 2000            | 2         | 5       | 10             | 4000                            | 40,000                        |
| (2) MASS MEMORY I/O      | S.R.         | 1300 | 1300            | 5         | 5       | 25             | 500                             | 12,500                        |
| (5) INTERCOMPUTER I/O    | S.R.         | 1500 | 1500            | 25        | 5       | 125            | 250                             | 31250                         |
| SUBROUTINE LIBRARY       | 2000         | -    | 2000            | -         | -       | -              | -                               | -                             |
| SUBTOTAL                 | 10,000       |      | 21800           |           |         |                |                                 | 673,150                       |
| SPARE AT 33% OF USED     |              |      | 7267            |           |         |                |                                 | 224,383                       |
| TOTAL                    |              |      | 29066           |           |         |                |                                 | 897,533                       |
| PROVIDED                 |              |      | 32768           |           |         |                |                                 | 1,000,000                     |

TABLE 3.3.4-3  
SMS MINICOMPUTER LOADING ESTIMATES  
FBCS DP&S MASTER CONTROLLER

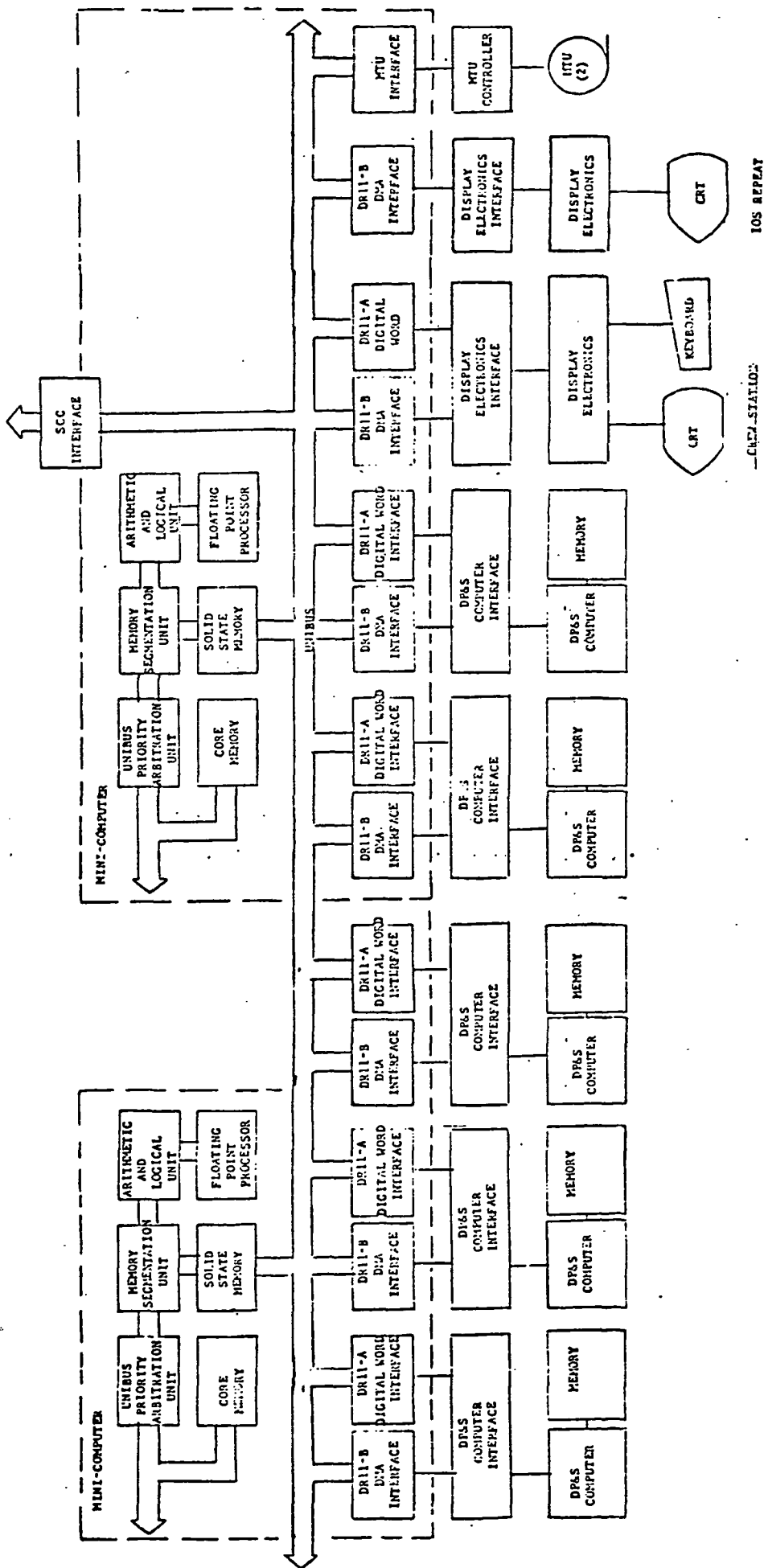
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## REVISIONS

| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|------|-----|-------------|------|----------|
|      |     | RELEASE     |      |          |



105 REPEAT

- CRT STATION

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|   |  |            |   |                             |         |
|---|--|------------|---|-----------------------------|---------|
| QTY REQD  |  | CODE IDENT | PART OR IDENTIFYING NO  | NOMENCLATURE OR DESCRIPTION | FINO NO |
| PARTS LIST  |  |            |   |                             |         |
| UNLESS OTHERWISE SPECIFIED<br>DIMENSIONS ARE IN INCHES<br>TOLERANCES ON DIMENSIONS<br>1 PLACE - 0.1 ANGULAR<br>2 PLACE - 0.01 FRACTIONAL<br>3 PLACE - 0.001 FRACTIONAL<br>4 PLACE - 0.0001 FRACTIONAL |  |            | CONTRACT NO   |                             |         |
| PREPARED BY   |  |            | DATE  |                             |         |
| CALCULATED  |  |            | TICKET  |                             |         |
| APPROVAL  |  |            | APPROVAL  |                             |         |
| DATE FORWARDED  |  |            | MAIL ROOM   |                             |         |
| UNLESS OTHERWISE SPECIFIED<br>DIMENSIONS ARE IN INCHES<br>TOLERANCES ON DIMENSIONS<br>1 PLACE - 0.1 ANGULAR<br>2 PLACE - 0.01 FRACTIONAL<br>3 PLACE - 0.001 FRACTIONAL<br>4 PLACE - 0.0001 FRACTIONAL |  |            | FIGURE 3.3.4-1<br>BLOCK DIAGRAM<br>FBCS OFF-BOARD COMPUTER SYSTEM |                             |         |
| THE SINGER COMPANY<br>SIMULATION PRODUCTS DIVISION<br>NEW YORK, N.Y. 10004  |  |            | SIZE CODE IDENT NO DWS NO REV                                     |                             |         |
| C 36378   |  |            | C 36378   |                             |         |

NOTE: UNIBUS WILL INTERCONNECT TO MDCS DP&amp;S SUBSYSTEM.

|         |           |         |
|---------|-----------|---------|
| DASH NO | NEXT ASSY | USED ON |
|---------|-----------|---------|

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|---------------------------|-------------------|--|--------|-------------------------|------------------|--|
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| PROGRAM ELEMENT           | INSTRUCTIONS DATA | TOTAL MEMORY                                       | RATE   | INSTRUCTIONS PER SECOND |                  |  |
| EXECUTIVE/MONITOR         | 6,000             | 6,000  |        | 10,000                  |                  |  |
| MASTER CONTROL AND TIMING | 1,000             | 1,000  |        | 4,000                   |                  |  |
| DP&S COMPUTER 1 INTERFACE | 2,000             | 2,600  | 600    | 75,000                  |                  |  |
| DP&S COMPUTER 2 INTERFACE | 2,000             | 2,600  | 600    | 75,000                  |                  |  |
| DP&S COMPUTER 3 INTERFACE | 2,000             | 2,600  | 600    | 75,000                  |                  |  |
| DP&S CRT DRIVE SYSTEM     | 2,000             | 5,000  | 3,000  | 25,000                  |                  |  |
| DP&S KEYBOARD             | S.R.              | 100  | 100    | 400                     |                  |  |
| SUB-ROUTINE LIBRARY       | 2,000             | 2,000  |        | --                      |                  |  |
| DATA FORMAT CONVERSIONS   | S.R.              | 500  | 500    | 40,000                  |                  |  |
| TOTALS                    | 17,000            | 5,400  | 22,400 | 304,400                 |                  |  |

TABLE 3.3.4-1  
SMS MINI COMPUTER LOADING ESTIMATE  
FBGS DP&S GN&C INTERFACE AND CONTROL

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| PROGRAM ELEMENT               | INSTRUCTIONS DATA | TOTAL MEMORY | RATE  | INSTRUCTIONS PER SECOND |
|-------------------------------|-------------------|--------------|-------|-------------------------|
| EXECUTIVE/MONITOR             | 6,000             | 6,000        |       | 10,000                  |
| MASTER CONTROL                | 1,000             | 1,000        |       | 4,000                   |
| DP&S COMPUTER NO. 4 INTERFACE | 2,000             | 2,600        | 600   | 75,000                  |
| DP&S COMPUTER NO. 5 INTERFACE | 2,000             | 2,600        | 600   | 75,000                  |
| MAG. TAPE UNIT CONTROL        | S.R.              | 100          | 100   | 1,000                   |
| SUB-ROUTINE LIBRARY           | 2,000             | 2,000        | -     | --                      |
| DATA FORMAT CONVERSION        | S.R.              | 500          | 500   | 40,000                  |
| TOTALS                        | 13,000            | 14,800       | 1,800 | 205,000                 |

TABLE 3.3.4-2

SNS MINI COMPUTER LOADING ESTIMATE

FBOS DP&amp;S AUXILIARY COMPUTER INTERFACE AND CONTROL

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| PROGRAM ELEMENT         | INSTRUCTIONS DATA | TOTAL MEMORY | RATE   | INSTRUCTIONS PER SECOND |
|-------------------------|-------------------|--------------|--------|-------------------------|
| EXECUTIVE/MONITOR       | 6,000             | 6,000        |        | 10,000                  |
| MASTER CONTROL & TIMING | 1,000             | 1,000        |        | 4,000                   |
| MAIN ENGINE CONTROLLER  | 6,000             | 6,400        |        | 150,000                 |
| MAIN ENGINES            | 2,000             | 3,200        |        | 150,000                 |
| SUBROUTINE LIBRARY      | 2,000             | 2,000        |        |                         |
| DATA FORMAT CONVERSIONS | S.R.              | 1,500        | 20     | 60,000                  |
| TOTALS                  | 17,000            | 3,100        | 20,100 | 374,000                 |

TABLE 3.3.4-3

SMS MINI COMPUTER LOADING ESTIMATE  
FBCS MAIN ENGINE SIMULATION, INTERFACE AND CONTROL



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### 3.3.5 FBCS Computer Complex

The Simulation Computer Complex for both the MBCS and FBCS is discussed in Section 3.2.5. Additions to the mini computer complement for the DCE, IOS CRT System, and On-board computers interfaces are also discussed in Section 3.3.4 and Section 3.3.6.

### 3.3.6 Data Conversion Equipment

The Data Conversion Equipment requirements for the FBCS are summarized in Table 3.3.6-1.

The technique which has been recommended for implementing these requirements has been completely described in Section 3.2.6.

Figure 3.3.6-1 is a block diagram of the FBCS baseline system.

The mini computer used for formatting and I/O control will also be utilized for the FBCS IOS CRT System control.

Table 3.3.6-2 identifies the software resident in this computer and the estimated loading in terms of memory and instructions per second.

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|                                | <u>Analog<br/>Input</u> | <u>Analog<br/>Output</u> | <u>Discrete<br/>Input</u> | <u>Discrete<br/>Output</u> | <u>ESRD</u> |
|--------------------------------|-------------------------|--------------------------|---------------------------|----------------------------|-------------|
| Fixed Base Crew Station        |                         |                          |                           |                            |             |
| Crew Station                   | 37                      | 177                      | 2192                      | 1737                       | 30          |
| Instructor/Operator<br>Station | 1                       | 117                      | 140                       | 417                        | 30          |
| Visual                         |                         |                          |                           |                            |             |
| Aural Cue                      |                         | 70                       |                           |                            |             |
| Voice Communications           |                         | 6                        |                           | 67                         |             |
| Sub Total                      | 38                      | 370                      | 2332                      | 2221                       | 60          |
| Spare at 25%                   | 10                      | 93                       | 583                       | 556                        | 15          |
| Total Required                 | 48                      | 463                      | 2915                      | 2777                       | 75          |
| Provided                       | 64                      | 480                      | 3584                      | 3072                       | 180         |
| Wired for Expansion To         | 96                      | 480                      | 3584                      | 3072                       | 108         |

Table 3.3.6-1  
FBCS DCE REQUIREMENTS

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| PROGRAM ELEMENT           | INSTRUCTIONS | DATA   | TOTAL<br>MEMORY | RATE | LOOPING | TOTAL<br>LOOPS | MICRO<br>SECONDS<br>PER<br>LOOP | MICROSECONDS<br>PER<br>SECOND |
|---------------------------|--------------|--------|-----------------|------|---------|----------------|---------------------------------|-------------------------------|
| EXECUTIVE MONITOR         | 6000         | 1000   | 7000            | 20   | 1       | 20             | 1,000                           | 20,000                        |
| MASTER CONTROL AND TIMING | 1000         | 200    | 1200            | 20   | 1       | 20             | 100                             | 2,000                         |
| ANALOG INPUT PROCESSING   | S.R.         | 144    | 144             | 20   | 48      | 960            | 9.1                             | 8,736                         |
| ANALOG OUTPUT PROCESSING  | S.R.         | 1389   | 1389            | 20   | 463     | 9,260          | 8.9                             | 82,414                        |
| END DRIVE                 | S.R.         | 75     | 75              | 20   | 75      | 1,500          | 7.4                             | 11,100                        |
| DIGITAL INPUT             | S.R.         | 3281   | 3281            | 20   | 183     | 7,660          | 6.8                             | 52,088                        |
| DIGITAL OUTPUT            | S.R.         | 4166   | 4166            | 20   | 5       | 100            | 20                              | 2,000                         |
| IOS CRT DRIVE             | 10,000       | 31,920 | 41,920          | 1    | 8       | 8              | 10,000                          | 80,000                        |
| SUBROUTINE LIBRARY        | 2,000        | --     | 2,000           |      |         |                |                                 |                               |
| SUBTOTAL                  |              |        | 61,275          |      |         |                |                                 | 407,350                       |
| SPARE AT 33% OF USED      |              |        | 20,425          |      |         |                |                                 | 135,783                       |
| TOTAL                     |              |        | 81,700          |      |         |                |                                 | 543,133                       |

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TABLE 3.3.6-2  
FBCS DCE AND IOS CRT CONTROL  
MINICOMPUTER LOADING ESTIMATE

|               |  |                  |
|---------------|--|------------------|
| DATE 12/21/73 | THE SINGER COMPANY<br>SIMULATION PRODUCTS DIVISION | PAGE NO. 3.3.6-2 |
| REV.          | BINGHAMTON, NEW YORK                               | REP. NO.         |

In the FBCS DCE minicomputer data buffers are required as follows:

|                  | SCC/Mini | Mini/I/O  | Total  |
|------------------|----------|-----------|--------|
| Analog Input     | 96       | 48        | 144    |
| Analog Output    | 926      | 463       | 1389   |
| Digital Input    | 2915     | 183 + 183 | 3281   |
| Digital Output   | 2777     | 1389      | 4166   |
| Sine Conversions | -        | 75        | 76     |
| Sub Total        |          |           | 9055   |
| IOS CRT Data     | 1520     | 30400     | 31920  |
| Total            |          |           | 40,975 |

Table 3.3.6-3 summarizes Input/Output data transfers from the FBCS DCE minicomputer. Base on these estimates, Unibus access time will be approximately 0.122 seconds per second for the FBCS.

# FBCS DCE MINICOMPUTER I/O

| SCC/MINICOMPUTER INTERFACE |       |            |                           |                             | MINICOMPUTER/SNS INTERFACE   |                  |                  |           |             |      |                  |
|----------------------------|-------|------------|---------------------------|-----------------------------|------------------------------|------------------|------------------|-----------|-------------|------|------------------|
| FUNCTION                   | SPARE | DATA WORDS | SCC FORMAT                | SCC/MINI I/O CHANNEL FORMAT | 16 BIT I/O CHANNEL HALFWORDS | I/O CHANNEL RATE | HALFWORDS/SECOND | HALFWORDS | FORMAT      | RATE | HALFWORDS/SECOND |
| ANALOG INPUT               | 25%   | 48         | 32 BIT FLOATING POINT     | 2 HALFWORDS                 | 96                           | 20               | 1,920            | 46        | FIXED POINT | 20   | 960              |
| ANALOG OUTPUT              | 25%   | 463        | 32 BIT FLOATING POINT     | 2 HALFWORDS                 | 926                          | 20               | 18,520           | 463       | FIXED POINT | 20   | 9,260            |
| DIGITAL INPUT              | 25%   | 2915       | 1 BIT PER 16 BIT HALFWORD | 2915 HALFWORDS              | 2915                         | 20               | 58,300           | 183       | BIT/BYTE    | 20   | 3,660            |
| DIGITAL OUTPUT             | 25%   | 2777       | 1 BIT PER 16 BIT HALFWORD | 2777 HALFWORDS              | 2777                         | 20               | 55,540           | 1382      | BIT/BYTE    | 20   | 27,780           |
| LOS CRT DISPLAY SYSTEM     |       | 30400      | MIXED                     | 1 HALFWORD                  | 1520                         | 20               | 30,400           | 30,400    | HALFWORD    | *(1) | 30,400           |
| FBCS SINE CONVERSION       |       |            |                           |                             |                              |                  |                  | 75(4)     | HALFWORD    | 20   | 6,000            |
| TOTAL                      |       |            |                           |                             |                              |                  | 164,680          |           |             |      | 78,060           |

\*(1) EIGHT CRT DISPLAYS UPDATED ONCE PER SECOND

TABLE 3.3.6-3  
FBCS DCE MINICOMPUTER I/O

DATE: 12/21/73

REV.:

SINGER-GENERAL PRECISION, INC.  
LINK DIVISION  
BIRMINGHAM, NEW YORK

PAGE NO. 3.3.6-20

REP. NO.

DATE 6/22/73

REV. -

SIMULATION  
COMPLEX

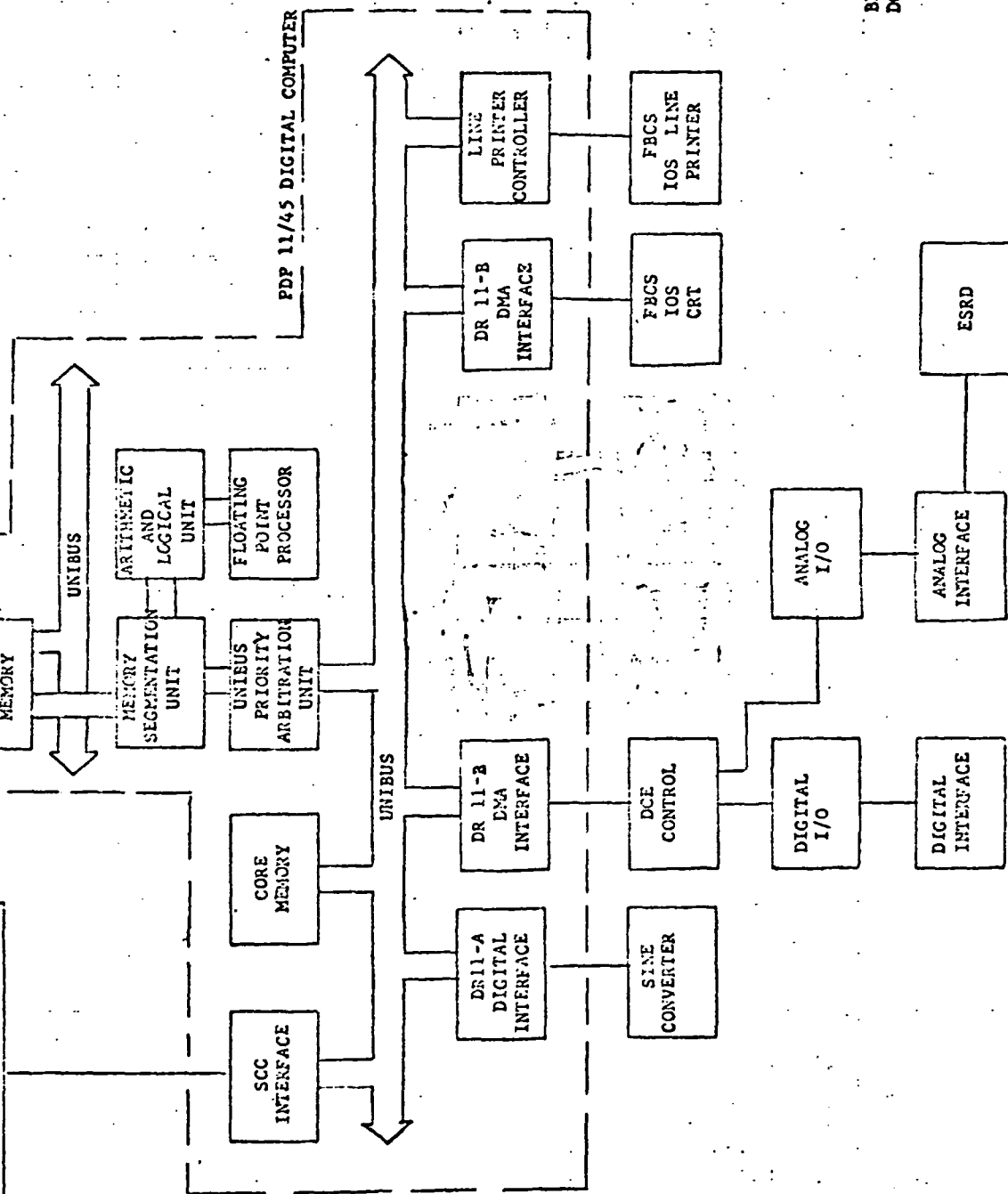


FIGURE 3.3.6-1  
BLOCK DIAGRAM FBCS  
DCE SYSTEM

| DATE 6/22/73                                |              | THE SINGER COMPANY<br>SIMULATION PRODUCTS DIVISION<br>BINGHAMTON, NEW YORK |              |              | PAGE NO. 3.3.6-4 |              |
|---|--------------|--|--------------|--------------|------------------|--------------|
| REV.  |              |  |              |              | REP. NO.         |              |
| PROGRAM ELEMENT                             | INSTRUCTIONS | TOTAL  | INSTRUCTIONS | INSTRUCTIONS | INSTRUCTIONS     | INSTRUCTIONS |
|   |              | MEMORY   | DATA         | PER SECOND   | PER SECOND       | PER SECOND   |
|   |              |  |              | RATE         |                  |              |
| EXECUTIVE/MONITOR                           | 6,000        | 6,000  | -            | 40           | 10,000           |              |
| MASTER CONTROL AND TIMING                   | 1,000        | 1,000  |              | 40           | 4,000            |              |
| DCE I/O DATA                                |              | 11,000   | 11,000       | 20           | -                |              |
| IOS CRT DATA                                |              | 25,600   | 25,600       | 20           | -                |              |
| SUB-ROUTINE LIBRARY                         | 2,000        | 2,000  | -            | -            | -                |              |
| ESRD SINE COSINE DATA                       |              | 340  | 340          | 20           | -                |              |
| DI UNPACK                                   | S.R.         | 3,200  | 3,200        |              | 14,400           |              |
| P.O. PROCESSING                             | S.R.         | 4,500  | 4,500        | 20           | 90,000           |              |
| FIXED/FLAT CONVERSIONS &<br>ANALOG DATA I/O | S.R.         | 1,100  | 1,100        | 20           | 66,000           |              |
| IOS CRT I/O DATA PROCESSING                 | 10,000       | 16,000   | 16,000       | 1            | 48,000           |              |
| TOTALS                                      | 19,000       | 61,740   | 70,740       |              | 232,400          |              |

TABLE 3.3.6-2  
SMS MINI COMPUTER LOADING ESTIMATE  
FBCS DCE AND IOS CRT CONTROL



DATE 6/22/73

THE SINGER COMPANY  
SIMULATION PRODUCTS DIVISION

PAGE NO. 3.3.7-1

REV.

BINGHAMTON, NEW YORK

REP. NO.

3.3.7 Visual Systems (TBD)

The Visual System design for the FBCS was not in the scope of the study.

DATE 6/22/73

THE SINGER COMPANY  
SIMULATION PRODUCTS DIVISION

PAGE NO. 3.3.8-1

REV.

BINGHAMTON, NEW YORK

REP. NO.

3.3.8 Miscellaneous Hardware

None required.